Ultrasonography

in Prehospital and Emergency Medicine

Rein Ketelaars

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Voor Selene en Annelies

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Chapter 1

Introduction, aims, and outline of this thesis

R. Ketelaars

Introduction

What is ultrasonography?

Ultrasonography is a diagnostic imaging technique based on high-frequency sound waves. In medicine, it is used to visualize organs and other structures inside the body. For instance, the heart, spleen, liver, kidneys, and major vessels as well as the chest wall and the surface of the lungs can be visualized. The aim is to detect or exclude pathology such as pericardial effusion, abnormal cardiac motility, free intraperitoneal fluid, a hemothorax or a pneumothorax. Besides these, there is a myriad of other indications for ultrasonography. Also, some therapeutic uses for ultrasound have been developed, as discussed in more detail in Chapter 2 of this thesis.

The human ear can perceive sounds with frequencies between 20 Hz and 20 kHz. The frequency of the sound waves used in ultrasonography lie well above the audible range and are therefore called ultrasound. In medical applications, the ultrasound frequencies are usually chosen in a range between 1 and 20 MHz. However, transducers with frequencies up to 71 MHz are on the market and ultrahigh frequency transducers of up to 300 MHz are in development.[1]

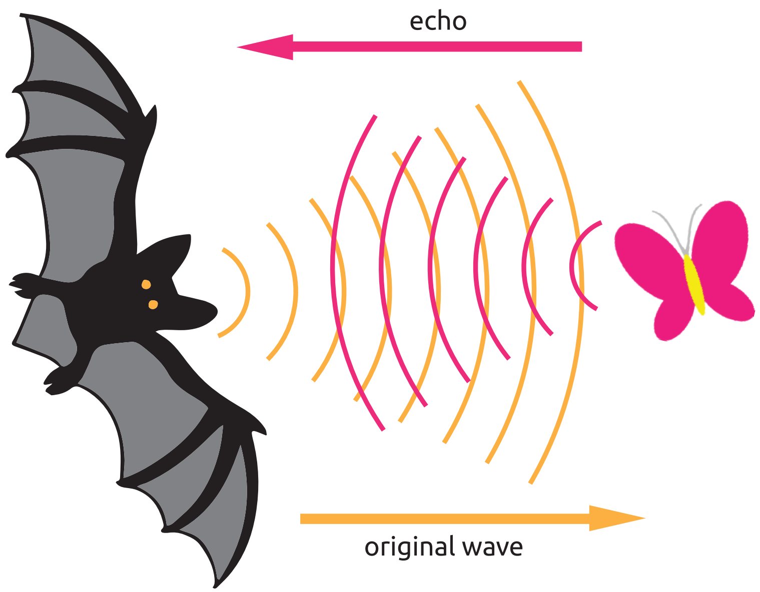

Figure 1.1 The reflection of ultrasound waves in the animal kingdom

A transducer contains a series of piezoelectric crystals that can convert electrical energy into ultrasound waves. These crystals can also receive the reflected ultrasound and convert it back into electrical energy that can be processed by the ultrasound machine's CPU to produce an image on the monitor.

The transducer is positioned on a body surface and the ultrasound waves are then conducted by tissues or fluids in the body. They are reflected back to the transducer to varying degrees by any structure they encounter. The greater the difference in conductive properties between adjacent tissues and fluids, the greater the proportion of ultrasound that is reflected by these tissues or fluids. Air and bone are the strongest reflectors. The reflected ultrasound waves are received by the transducer and used to construct an image of the area of interest. For instance, this same principle is found in nature (Figure 1.1) and marine technology (Figure 1.2). Examples of ultrasound images in medicine are displayed in Figure 1.3 and Figure 1.4.

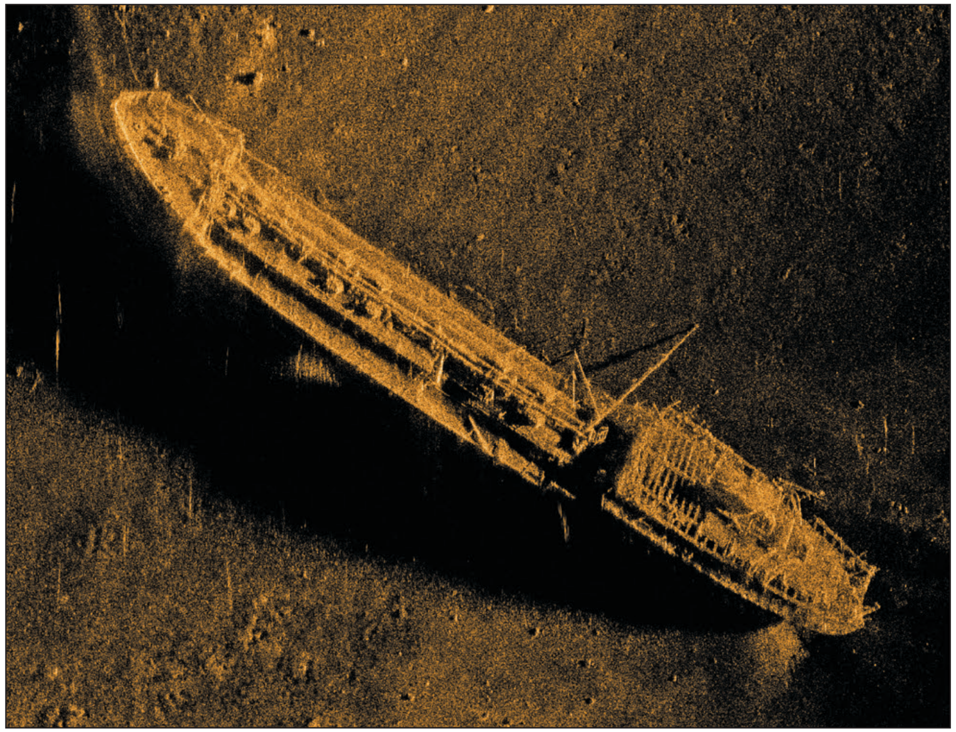

Figure 1.2 Sonar image of the wreckage of the 1500 dwt German oil tanker "Holmengraa"

It is lying on the slanted seabed off Horten, Vestfold, south of Oslo, Norway, at a depth of 77 m. It sank on 28 December 1944 as a result of an allied forces bombing. It was discovered in 1994.

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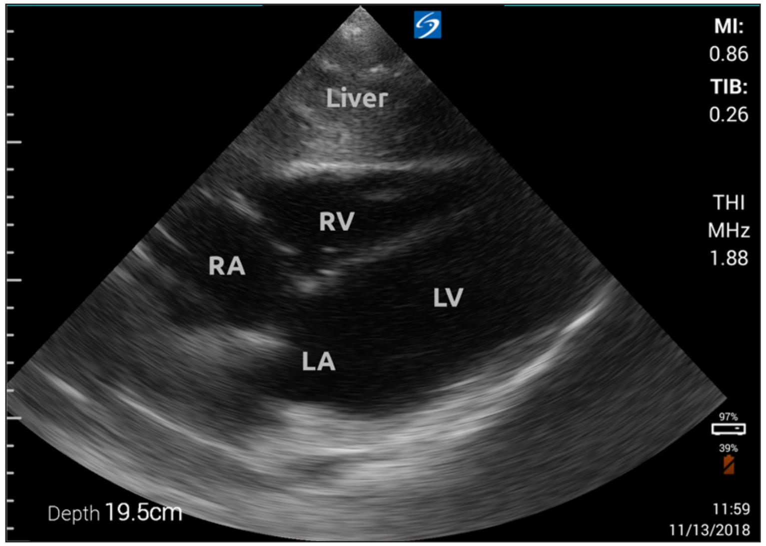

Figure 1.3 An ultrasound image of the heart

LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

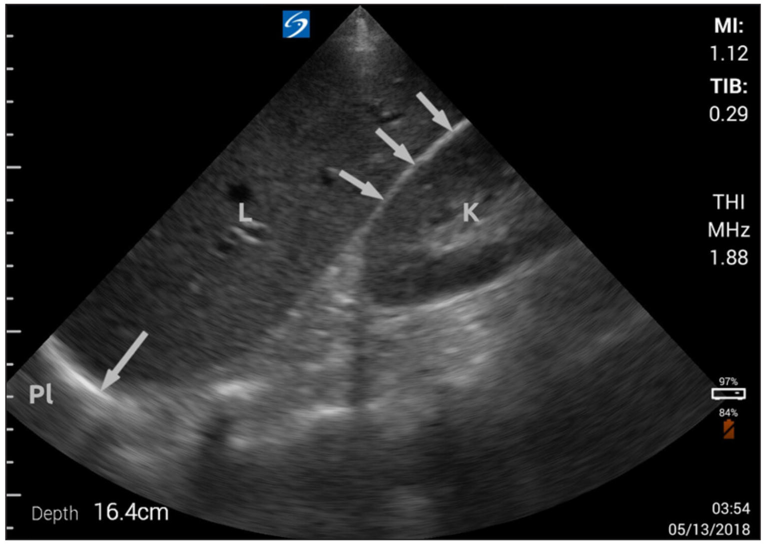

Figure 1.4 An ultrasound image of the right upper abdominal quadrant

The hepatorenal recess or Morison's pouch is indicated by the small arrows. The larger arrow indicates the diaphragm.

L, liver; Pl, pleura; K, kidney.

An ultrasound wave travels through human tissue always at roughly the same speed of 1540 meters per second. Because this speed is more or less constant, the wavelength of the ultrasound wave depends on the frequency of the oscillations in the wave as shown in Figure 1.5 and Figure 1.6. This relation between the wave speed (c), wavelength (λ) and frequency (f) is stated by the wave equation: $c = \lambda \times f$ or $\lambda = c / f$. When the frequency increases, the wavelength gets shorter and vice versa.

Why is this important? The depth of penetration of an ultrasound wave is determined by its frequency and thus the number of oscillations/wavelengths for a certain distance the sound waves have traveled. The higher these numbers are, the shallower tissue penetration is.

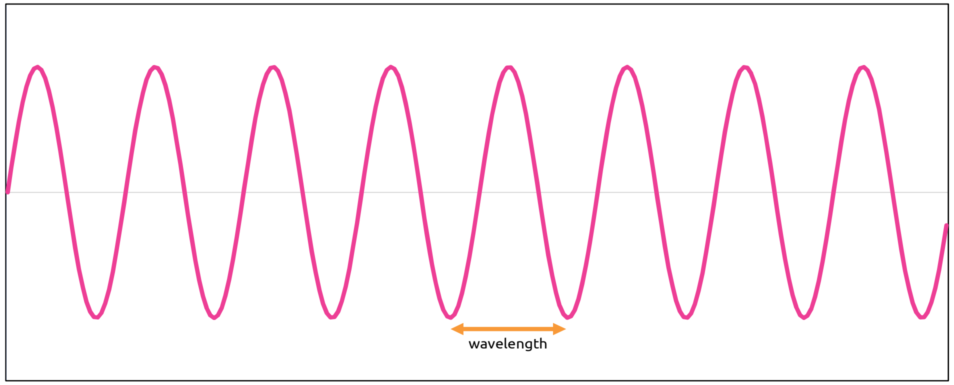

Figure 1.5 High-frequency ultrasound wave

The speed of the wave stays the same, a high frequency results in a shorter wavelength.

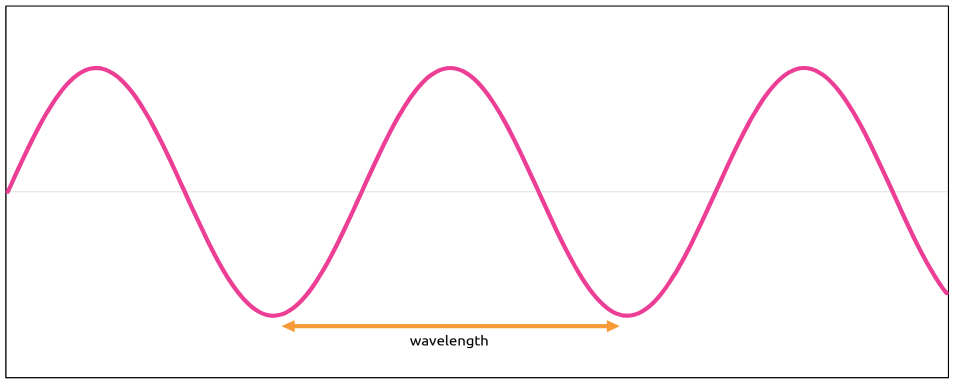

Figure 1.6 Low-frequency ultrasound wave

The speed of the wave stays the same, a low frequency results in a longer wavelength.

Inversely, ultrasound waves penetrate deeper with lower frequencies and thus a lower number of oscillations/wavelengths for a traveled distance. For instance, common low-frequency transducers (frequency range of 5–1 MHz) can visualize structures at a depth of up to 35 cm.

However, the trade-off here is that the resolution of the ultrasound image is determined by the wavelength of the ultrasound wave in the tissue. A longer wavelength, emitted by low-frequency transducers, will yield a lower image resolution compared to high-frequency (short wavelength) transducers. This trade-off between tissue penetration and wavelength (and thus image resolution) is displayed in Figure 1.7.

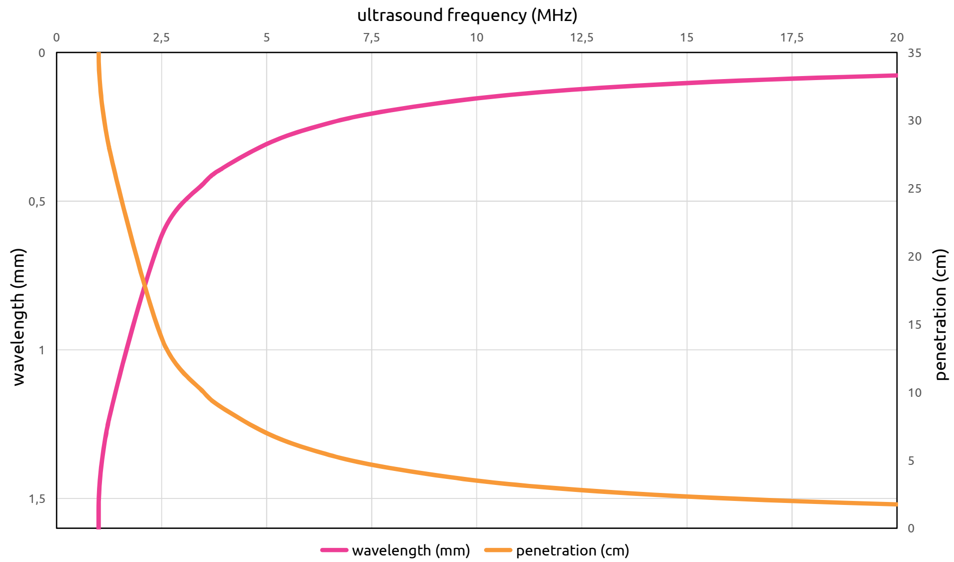

Figure 1.7 Ultrasound penetration vs wavelength and resolution

Pros and cons of ultrasonography

Ultrasonography is almost entirely harmless because sound waves are used instead of harmful electromagnetic waves such as X-rays. No long-term side effects are known and it rarely causes any discomfort to the patient. Therefore, image acquisition can be repeated without penalty. Ultrasonography produces live images, allowing to support decision-making in real-time. It is reproducible, repeatable, and relatively low-cost. Highly portable equipment is available and can therefore be brought to the bedside such as in the emergency department (ED), the intensive care unit (ICU), and in the prehospital setting. It is easy to learn, although adding experience improves successful image acquisition and the diagnostic performance of the technique.[2]

There are also some disadvantages. The field of view may be limited, depending on both the transducer type and the presence of bone or air preventing further penetration of ultrasound. The image quality may be reduced by body habitus or limited access caused by clothing or defibrillator pads. Furthermore, the level of training and experience of the operator determines the success and quality of image acquisition, the interpretation of the images and thus the diagnostic performance of ultrasonography.

A short history of ultrasonography

Medical ultrasonography made its appearance shortly after the second world war. It was first described by Karl Theo Dussik in 1942 and he published the first ultrasound images in 1947.[3,4] At that time, the technology consisted of huge machines that produced low-quality images. Although ultrasound devices became increasingly portable, it took over 35 years before the first report on prehospital ultrasonography (PHUS) was published in 1983.[5] The authors described the successful use of a portable ultrasound device in prehospital patients by the French emergency medical services; Service d'Aide Médicale Urgente (SAMU).

To put this into perspective, both the pulse oximeter and the colorimetric CO2-detector were introduced in the prehospital setting around 1988.[6,7] And the prehospital use of portable quantitative waveform capnography was first reported in 1994.[8]

Before then, the assessment of prehospital patients relied on history-taking, physical examination, blood pressure measurements and electrocardiography. A physical examination traditionally consists of observation, auscultation, percussion, and palpation. Similarly, the Advanced Trauma Life Support (ATLS) course dictates to look, listen, and feel to conduct an initial assessment in trauma patients.[9] A noisy emergency department or—even worse—the noisy prehospital environment poses a serious challenge to those who attempt to reliably evaluate injured or critically ill patients. This challenge is aggravated by the ever-present time pressure, limited working space, excessive heat or cold, and other environmental factors.

Through physical examination alone, it is hard to diagnose a (simple) pneumothorax. During the primary evaluation of trauma patients, auscultation of the chest (using a stethoscope) has a sensitivity to detect a hemothorax, hemopneumothorax, or pneumothorax of only 58%.[10] Others reported that auscultation for (hemo)pneumothorax has a sensitivity of 59–66%.[11,12] Besides (hemo)pneumothorax, the detection of intraperitoneal free fluid, pericardial effusion or tamponade, or endobronchial (as opposed to endotracheal) intubation may be as hard, or even harder![13]

The introduction of ultrasonography in emergency medicine has now made it possible to diagnose these conditions with far greater accuracy. In 1988 Filly recognized ultrasound to potentially be the 'stethoscope of the future' although he expressed some concerns about nonradiologists adopting ultrasonography.[14] Also, Isono stated in an editorial in Anesthesiology that "perhaps the stethoscope is closer to a costume piece than ever before," meaning that its days might be numbered since the advent of ultrasonography.[15] Others also recognized that ultrasonography may well be 'the stethoscope of the 21th century' and might one day replace it.[16,17]

For a long time, (noncardiac) ultrasonography was solely the domain of radiologists. When nonradiologists such as emergency physicians started embracing point-of-care ultrasonography (PoCUS), many radiologists were concerned about substandard quality of diagnostic imaging that would negatively impact patient care, safety, and related costs.[18,19] In more recent years, however, PoCUS by nonradiologists has become more common. Nevertheless, the discussion in literature continues.[20–23]

Ultrasonography in Dutch helicopter emergency medical services (HEMS)

Prehospital emergency ultrasonography was introduced in the Netherlands in 2006 by Gerritse, Dirven, and Huig.[24] From Nîmes, France, they imported an emergency ultrasound training called the Programme Rapide d'Échographie d'un Polytraumatisé or Polytrauma Rapid Echo-evaluation Program (PREP). The PREP philosophy is to seek the answer to a primary set of simple yes/no questions: are there any signs of a (large) pneumothorax, hemothorax, free intraperitoneal fluid or air, pericardial effusion, or an aneurysm of the abdominal aorta?[24] Apart from the abdominal aorta measurement, the PREP approach is similar to the extended focused assessment with sonography for trauma (eFAST).[25]

The first course was organized on February 2nd, 2006 in Loosdrecht, the Netherlands. Simultaneously, the HEMS of Nijmegen and Rotterdam adopted the advantages of PHUS by bringing a portable ultrasound machine to emergencies. In the years to come, many HEMS physicians and emergency physicians (amongst others) successfully completed the course. After the course has been running for some years, we were interested in what kind of impact the PREP training had made on the use of ultrasound by emergency physicians in daily practice. How did they handle the implementation of ultrasonography in Dutch emergency departments?

In the Nijmegen HEMS, the first ultrasound machine we carried on board was a Fujifilm SonoSite® MicroMaxx® ultrasound device (Figure 1.8). Later, it was replaced by the more compact and robust NanoMaxx® device (Figure 1.9). A few years later, it was superseded by an M-Turbo® device (Figure 1.10, a look-alike of the MicroMaxx® device, but with improved internals) and in 2017 by the iViz® system (Figure 1.11). These devices were equipped with both a 5–1 MHz phased-array transducer and a 10–5 MHz or 15–6 MHz linear-array transducer.

With this choice of transducers, the question arose which transducer should be connected with the device as a first choice. Probably, the first or most urgent indications would be the evaluation of the chest or the airway.

Figure 1.8 MicroMaxx® ultrasound device

The first ultrasound device on the Nijmegen HEMS.
Dimensions: 8.0 × 27.7 × 30.2 cm – weight: 3.50 kg.

Figure 1.9 NanoMaxx® ultrasound device

An L38 10–5 MHz linear-array transducer is attached. It was the third ultrasound device on the Nijmegen HEMS.
Dimensions: 20.8 × 35.8 × 5.8 cm – weight: 2.72 kg.

Figure 1.10 M-Turbo® ultrasound device

The third ultrasound device on the Nijmegen HEMS.
Dimensions: 8.0 × 27.7 × 30.2 cm – weight: 3.50 kg.

Figure 1.11 SonoSite iViz® ultrasound device

A P21v 5–1 MHz phased-array transducer is attached. It was the Nijmegen HEMS's fourth ultrasound device.
Dimensions: 11.7 × 18.3 × 2.7 cm – weight: 0.52 kg.

Images reproduced with permission and by courtesy of Tom Fugers, SECMA B.V., Vianen, the Netherlands.

Dutch HEMS

In the Netherlands, four HEMS teams are operational. They operate as an adjunct to the land-based ambulance service. The aim is to transport an expert physician and nurse to critically ill and injured patients to deliver hospital-level medical care.

The four HEMS are affiliated with four Level 1 trauma centers: VU University Medical Center (VUmc) Amsterdam, Erasmus University Medical Center (ErasmusMC) Rotterdam, Radboud university medical center (Radboudumc) Nijmegen, and University Medical Center Groningen (UMCG). In 1995, the Amsterdam (Lifeliner 1) HEMS was the first to be operational in the Netherlands. The Nijmegen HEMS (Lifeliner 3) made its maiden voyage on March 1st, 2001.

At present, the helicopters and pilots are provided by the Royal Dutch Touring Club (Koninklijke Nederlandse Toeristenbond) ANWB.

In 2018 the Nijmegen HEMS performed 2895 scrambles and in January 2018 its crews treated their 10,000th patient since modern record-keeping started in 2007.

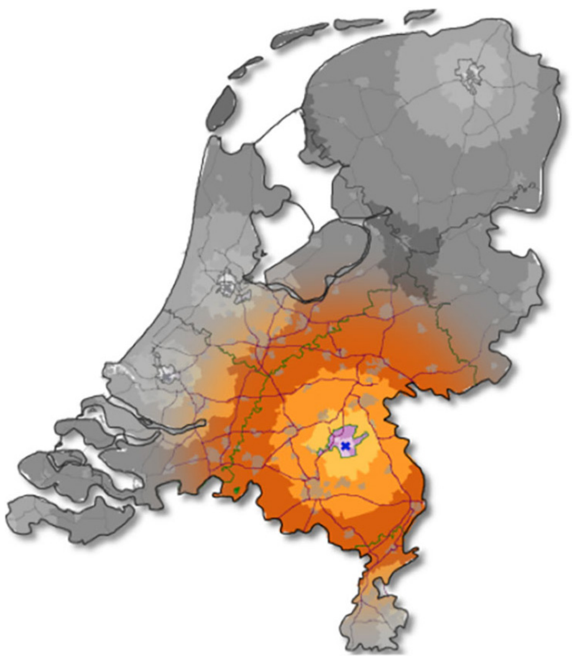

Figure 1.12 The Nijmegen HEMS is stationed at the Volkel Air Force Base

The Nijmegen HEMS is stationed at the Volkel Air Force Base and services an area of roughly 10,000 km² with 4.5 million inhabitants (Figure 1.12). When required, however, they can be deployed throughout the country including parts of the German territory.

A HEMS team consists of a pilot, a helicopter crew member (HCM), and a physician. Many pilots have got a military/air force background. The HCMs are ambulance nurses or ED nurses with extensive clinical or preclinical experience. Some are also qualified as a nurse anesthetist. Their main tasks are flight planning, navigation, and the assistance of the pilot in-flight by maintaining a safe lookout and with emergency procedures. On-scene, the HCM is involved in patient care. The physicians are medical specialists: either a trauma surgeon or an anesthesiologist. They have experience and are trained in the care for the (prehospital) injured and critically ill patients. One mandatory element of that training is a PREP or eFAST ultrasound course.

The evolution of ultrasonography in Dutch HEMS

Initially, PHUS was used for the indications taught to the Dutch HEMS physicians in the PREP course. These include the detection or exclusion of a pneumothorax, hemothorax, free intraperitoneal fluid or air, pericardial effusion, and an abdominal aorta aneurysm.[24]

Later, the HEMS physicians started using PHUS for additional indications. Ultrasound-guided airway management (discussed in **Chapter 2**) has been used to assess the airway before intubation or to visualize the larynx and proximal esophagus in real-time while an attempt was made to intubate the trachea.

Also, ultrasound-guided regional anesthesia (UGRA) (**Chapter 5**) was recognized to be of benefit in patients with extensive extremity injuries. UGRA proved to be especially useful in patients with a trapped arm or leg that prevented them leaving the incident location. Superior pain relief can be achieved while it might take some amount of time for their extremities to be released and for in-hospital loco-regional pain treatment or surgery to be started.

Optical nerve sheath diameter (ONSD) measurements (**Chapter 9**) were carried out to detect a possible rise in intracranial pressure (ICP) as a sign of intracranial pathology. It might support the decision to either transport the patient to a neurosurgical center or to the nearby general hospital.

Nowadays, PHUS has become an established diagnostic tool in Dutch HEMS. This development did not go unnoticed by the ground ambulance services. Occasionally, they even request the HEMS to proceed to the incident location, specifically to perform diagnostic ultrasonography. In the not too distant future, ground ambulance nurses will, without a doubt, perform their own PHUS scans.

The body of literature on emergency ultrasonography in the prehospital setting, however, is still relatively manageable. Especially in the early days of this PhD project, the papers on, for instance, prehospital chest ultrasonography and prehospital peri-resuscitation focused cardiac ultrasonography were scarce. Papers on prehospital ONSD measurements were non-existent. Therefore, in the Nijmegen HEMS, the need arose to evaluate the use of prehospital

ultrasonography to evaluate our own practice and to add to the literature.

Ultrasonography beyond the HEMS

HEMS physicians are involved in ultrasonography outside of the scope of the HEMS.

A handful of HEMS physicians (in collaboration with emergency physicians and an orthopedic surgeon) are involved in the PREP ultrasound course, as discussed hereabove. They are enthusiastic about emergency ultrasonography and have been motivated to teach the skill to many colleagues over the years. Many candidates completed the course, including emergency physicians, anesthesiologists, surgeons, HEMS physicians, internists, intensivists and Dutch army medical imaging technologists.

Besides teaching, Nijmegen emergency physicians (EPs) and HEMS physicians are collaborating since 2014 to introduce UGRA in the emergency department. The EPs purchased a modern portable ultrasound device, equipped with three transducers, to be used for more than UGRA alone, obviously. Together they developed a one-day UGRA course for EPs and emergency medicine residents. Subsequently, they started performing nerve blocks; mainly femoral nerve blocks in patients with proximal femoral fractures. On request, (resident) anesthesiologists supervised the performance of the blocks. The EPs carried out continuous and accurate quality control by keeping a record of all nerve blocks.

Future

The quality and portability of ultrasound devices is increasing. Simultaneously, their size, weight, and price are coming down. Also, the body of evidence in the literature and the number of indications is growing. Therefore, ultrasonography will be embraced by a growing number of health care workers and it will be applied in a growing number of patients to improve decision-making and the care they receive. And ultimately benefits in morbidity and mortality will become apparent. Potential future PHUS applications will be discussed in **Chapter 2** and **Chapter 10**.

With the growing adoption and utility of ultrasonography, few will be surprised that it has been called "the visual stethoscope of the 21th century".[16] And this might be especially true in the dynamic and noisy prehospital environment.

Aims and outline of this thesis

Aims

The main aim of this thesis is to explore the impact of ultrasonography in prehospital and emergency medicine.

The first objective is to discuss the current state of literature and evaluate a selection of transducers. The second is to evaluate the implementation and utility of ultrasonography in the ED, in the HEMS, and in the future, and how it impacts the care for both critically ill and injured patients.

Outline

This thesis describes the results of the studies conducted to investigate the implementation, impact, and utility of ultrasonography in prehospital and emergency medicine.

In **Part I**, we will focus on the background of emergency and prehospital ultrasonography. The aim is to learn from existing knowledge and from existing technology.

In **Chapter 2**, a narrative review of the literature on prehospital ultrasonography is presented. The aim will be to focus on current and future applications of prehospital ultrasonography, both for diagnostic and therapeutic use. We will highlight ultrasound applications in the emergency department and in other settings such as clinical, military, and wilderness medicine, that also appear to be feasible for future prehospital use. Also, we will highlight some of the pitfalls of prehospital ultrasonography.

Since the introduction of PHUS to the Nijmegen HEMS, we primarily used a 5–1 MHz phased-array cardiac transducer. With a growing interest in new indications for prehospital ultrasonography, the need for applications for the linear-array transducer was also increased. In **Chapter 3**, we describe the difference in performance of three types of ultrasound transducers for the detection of pneumothorax. We recorded ultrasound video clips in pneumothorax patients (i.e. thoracoscopy patients). The clips were blinded for diagnosis and transducer type and were evaluated by prehospital HEMS physicians and experienced anesthesiology residents. Outcomes are the diagnostic accuracy, speed until final diagnosis, and image quality.

In **Part II**, we will highlight aspects of the implementation of ultrasonography in the emergency department.

To have a better understanding of how emergency physicians experience the implementation of ultrasonography after having received an emergency ultrasonography training, we conducted interviews in Dutch emergency physicians who successfully completed the two-day PREP course as discussed above. The focus was on the incentives to start using ultrasonography, on its practical application, and on the challenges the emergency physicians may have met in the implementation process. In **Chapter 4**, the results of this qualitative study will be discussed.

HEMS physicians collaborated with emergency physicians and emergency medicine residents to introduce ultrasonography in the emergency department and to develop a training in ultrasound-guided regional anesthesia. In **Chapter 5**, we describe the implementation and performance of ultrasound-guided femoral nerve blocks by emergency physicians and residents in patients with proximal femoral fractures.

After having focused on the background of emergency and prehospital ultrasonography and on implementation in the emergency department, the next part will focus on ultrasonography in the Nijmegen HEMS. In **Part III**, we will focus on the impact of PHUS on the treatment of both critically ill and injured patients by the Nijmegen HEMS.

As discussed above, the classic physical examination of both critically ill and injured patients may be challenging in prehospital and emergency medicine. Depending on the diagnosis, for instance pneumothorax or hemothorax, its diagnostic accuracy can be disappointing.[10–12]

Chapter 6 describes a retrospective evaluation of prehospital chest ultrasonography in 281 patients treated by the Nijmegen HEMS over a four-year period. We focus on the impact of chest ultrasonography on the care for prehospital patients.

The value of physical examination alone in the evaluation of blunt abdominal trauma is also limited.[26] To evaluate the impact of prehospital abdominal ultrasonography on patients treated by the Nijmegen HEMS, we conducted a retrospective database analysis. In **Chapter 7**, we describe the analysis of the management of 1583 patients that were treated in a 10-year period. The aim was to determine the accuracy of abdominal PHUS and its impact on treatment decisions.

Echocardiography is widely regarded as a valuable adjunct to the cardiopulmonary resuscitation of critically ill or injured patients.[27] It improves the diagnostic accuracy of treatable causes of cardiac arrest compared to physical examination alone.[28,29] We performed an observational study on prehospital echocardiography during the cardiopulmonary resuscitation of 56 patients treated by the Nijmegen HEMS. We focused on the impact of echocardiography on treatment decisions. The results are discussed in **Chapter 8**.

In **Part IV**, the attention will be directed to the future of prehospital ultrasonography.

Sonographic measurement of the optical nerve sheath diameter (ONSD) is an example of a PHUS application that still is waiting to conquer a solid position in prehospital emergency medicine. In patients suffering from traumatic brain injury (TBI), the intracranial pressure (ICP) may be elevated, often caused by swelling of the brain parenchyma or by space-occupying intracranial hematomas. An ICP elevation may also be caused by an impairment of venous drainage from the intracranial space, for instance because of a tightly applied rigid cervical collar. An elevated ICP manifests itself in many ways, but one of them is an increase in the ONSD.[30] In a collaboration with dr. Maissan from the Rotterdam ErasmusMC and Lifeliner 2 HEMS station, we conducted repeated sonographic ONSD measurements in healthy volunteers. Between measurements, blinded to the researchers, they were randomly donned a rigid cervical collar, to evaluate the impact of this collar on intracranial venous drainage and possibly on the ICP and thus ONSD in healthy subjects. This study and its main findings are discussed in **Chapter 9**.

Chapter 10 provides a summary of the conclusions of this thesis, discussion and future perspective; **Chapter 11** provides a summary of the conclusions, discussion and future perspective in Dutch.

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Part I

Background of ultrasonography in prehospital emergency medicine

Chapter 2

ABCDE of prehospital ultrasonography: a narrative review

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Abstract

Prehospital point-of-care ultrasound used by nonradiologists in emergency medicine is gaining ground. It is feasible on-scene and during aeromedical transport and it allows healthcare professionals to detect or rule out potential harmful conditions. Consequently, it impacts decision-making in prioritizing care, selecting the best treatment, and the most suitable transport mode and destination. This increasing relevance of prehospital ultrasonography is due to advancements in ultrasound devices and related technology, and to a growing number of applications.

This narrative review aims to present an overview of prehospital ultrasonography literature. The focus is on civilian emergency (trauma and non-trauma) setting. Current and potential future applications are discussed, structured according to the airway, breathing, circulation, disability, environment/exposure (ABCDE) approach. Aside from diagnostic implementation and specific protocols, procedural guidance, therapeutic ultrasound, and challenges are reviewed.

Background

Point-of-care ultrasound (PoCUS) refers to a sign or symptom-based ultrasonography (US) examination either at the bedside or wherever patients are being treated.[1] The use of PoCUS by nonradiologists is being adopted in prehospital emergency care. It may help healthcare professionals of emergency medical services (EMS) to diagnose or rule out potential life-threatening or otherwise harmful conditions.[2–4] Prehospital point-of-care ultrasonography (PHUS) may have an impact on decision-making in prioritizing initial treatment and choosing the most appropriate hospital and mode of transportation.[5,6] Besides deploying PHUS for diagnostic purposes, it is used for procedural and therapeutic interventions.

Although the use of PHUS is increasing, its added value is still under debate. In 2010, Jørgensen was unable to conclude that PHUS improves treatment of trauma patients.[5] Five years later, O'Dochartaigh found only moderate evidence to support the use of PHUS in physician-staffed prehospital systems.[6] A recent Cochrane review concluded that, at best, abdominal US has no negative impact on mortality and morbidity, although it might reduce ordered computed tomography (CT)-scans.[7] Rudolph et al. found that PHUS may improve patient management with respect to diagnosis, treatment, and hospital referral.[8] However, they were unable to assess the effect of PHUS on patient outcomes based on the current body of evidence.

The image quality, size, and weight of portable ultrasound devices are improving. Costs for equipment are decreasing while the number of indications for PHUS is increasing. The result is an exponentially growing body of publications, including some narrative reviews, with varying perspectives.[9–11]

This narrative review is based on relevant papers selected from an extensive search in the Ovid MEDLINE® database (Appendix A). The search produced 2315 hits. We excluded 1932 papers based on their titles and read 383 abstracts to exclude another 232. We included most of the 151 remaining papers based on their relevance to the subject of this review. Furthermore, we added additional papers found in the references and from the authors' personal libraries.

The aim is to present an overview of the literature on PHUS in a civilian emergency (trauma and non-trauma) setting. The first part deals with current PHUS applications structured according to the familiar airway, breathing, circulation, disability, and exposure/environment (ABCDE) approach.[12] The second part will discuss interventions, procedures, challenges, and potential future applications.

PHUS in general

The use of PHUS provides diagnostic and therapeutic benefit, and it does not delay patient management.[3,8,13–15] It has been found to be feasible to enhance clinical assessment in a variety of out-of-hospital settings.[15] Price was among the first to show that ultrasonography (US) is also feasible during helicopter transport and that focused assessment with sonography for trauma (FAST) can be rapidly performed in-flight and has no influence on aircraft avionics.[16]

Physicians and paramedics without being educated as a radiologist can be trained effectively to perform PoCUS. Lyon et al. demonstrated that prehospital critical care providers could learn to detect the sonographic sliding lung sign with a high level of sensitivity (97%) and specificity (94%) and retain their skill over time.[17] Forty physicians participated in a 4-hour hands-on training and demonstrated significant improvements in the ability to perform US examinations.[18] Although the initial learning curve for FAST is steep, it starts to flatten after 30-100 scans.[19] Probably even more training and experience is required for advanced applications such as transcranial doppler for ischemic stroke or specific triage protocols.

With the right education and mentorship, paramedics can obtain ultrasound images of sufficient quality to positively identify significant pathologies in critically ill patients.[20] A recent Canadian study found that PHUS performed by both physicians and non-physicians supported interventions in both trauma and medical patients.[21]

The reported diagnostic accuracy of PHUS varies widely. Some reported a sensitivity of 85–90% and a specificity of 96–100% for chest, abdominal, and cardiac US. Positive predictive value (PPV) and negative predictive value (NPV) were 100% and 95.5%.[3,13] Diagnostic accuracy during transportation also varies. For PHUS during transfer by ground ambulance and PHUS on-scene, Brun reported a sensitivity of 94.7% and 95.2%, respectively.[22] In-flight ultrasound examinations of the lung, abdomen, and pericardium yielded a sensitivity of only 50–64.7% when compared to pathology that required an intervention, rather than to all positive findings.[23] Others found a sensitivity of 78.6% for in-flight extended FAST (eFAST) compared to CT-scan.[24] Because of the high specificity, the activation of a trauma surgery team is justified for positive PHUS findings.[23]

Despite the range in diagnostic accuracy, PHUS is still highly reliable compared to clinical assessment.[3,5] In 169 non-trauma patients, PHUS improved the diagnostic accuracy based on traditional clinical examination to 67% compared to the final in-hospital diagnosis. Diagnostic accuracy was improved in 90% of patients in whom the initial diagnosis was uncertain (n = 115).[25] Blaivas found that PHUS improved the certainty of the diagnosis in 68% of 25 mainly non-trauma patients.[26]

PHUS potentially impacts life-saving procedures, priorities in the care for one or many patients, and the most appropriate destination. Indications exist that PHUS benefits outcome, but evidence is still lacking.[5] Nevertheless, O'Dochartaigh and Jørgensen noted that PHUS impacted and streamlined in-hospital treatment.[5,6] The impact was not quantified, but O'Dochartaigh suggested that PHUS-supported interventions were more frequent in the more severely injured patients.

2

Diagnostic applications

A – Airway

First-attempt success rates of prehospital rapid sequence intubations vary between 46% and 85%.[27] An attempt fails when the endotracheal tube (ETT) cannot be placed between the vocal cords in the trachea or is inadvertently placed in the esophagus. It is of paramount importance to acknowledge esophageal intubation as soon as possible.

The use of tracheal and cricothyroid ultrasound can be very useful to confirm correct ETT placement. This was first described in neonates by Slovis in 1986.[28] Fourteen years later, Dreschler was the first to also visualize the esophagus and to detect esophageal intubation in five out of five cadaver models.[29] A recent review showed a pooled sensitivity and specificity of respectively 98% and 94% of transtracheal US in emergency intubations.[30] Therefore, the confirmation of correct ETT position by PoCUS in the prehospital setting is likely to be beneficial.[12,31,32] Although capnography is considered the gold standard to confirm a correct tube position, it doesn't discriminate between endotracheal or endobronchial intubation.[33] Furthermore, in a prehospital setting, chest radiography is impossible, and auscultation is not always feasible. Therefore, PHUS might be a valuable tool to assess the airway.[34]

Zadel et al. confirmed endotracheal tube position by the detection of bilateral lung sliding and bilateral diaphragmatic excursion in 124 out-of-hospital patients.[32] Esophageal intubation occurred in 13 patients (10.5%) of which only 30% was detected visually or by auscultation before waveform capnography was recorded. Both sensitivity and specificity of PHUS for a correct tube position was 100%. The performance of PHUS took a median of 30 s (*SD* = 8–120 s). A prospective study in pediatrics preferred the assessment of bilateral diaphragmatic excursions to confirm proper ETT placement.[35] Therefore, the assessment of lung sliding and diaphragmatic excursions is of value in the absence of chest radiography or capnography.

B – Chest, pulmonary

The cause of acute dyspnea is not immediately apparent, especially in the prehospital setting. Caregivers must differentiate between a cardiac or a pulmonary cause. In an emergency department (ED)-study, Kajimoto proposed a quick method to integrate (1) lung ultrasound, (2) cardiac ultrasound, and (3) measurements of the inferior vena cava (LCI).[36] Lung ultrasound is performed in eight chest areas (four anterior and four lateral). Cardiac ultrasound estimates the global left ventricular function and mitral or tricuspid valve regurgitation. Subsequently, collapsibility of the inferior vena cava is determined. The LCI integrated examination will take only up to three minutes. The sensitivity and specificity were 94.3% and 91.9% for acute heart failure syndromes, compared to the traditional methods of differentiating between pulmonary and cardiac causes including electrocardiogram, chest X-ray and B-type natriuretic peptide (BNP).

A similar triple scan consisting of basic echocardiography, lung ultrasound, and assessment of inferior vena cava collapsibility was proposed by Mantuani et al.[37] They included 57 patients with acute dyspnea caused by acute decompensated heart failure (ADHF), chronic obstructive pulmonary disease (COPD), and pneumonia. After the triple scan, the accuracy of the diagnosis, based on history and physical examination, increased from 53% to 77%. Sensitivity and specificity of the triple scan for ADHF were 100% and 84%.

Lichtenstein's bedside lung ultrasound in emergency (BLUE) protocol allows rapid diagnosis of acute respiratory failure and can be completed in under three minutes.[38,39] Four standardized points on either side of the chest are assessed for ten signs indicative of normal lung surface, pleural effusions, lung consolidations, alveolar-interstitial syndrome, and pneumothorax. For simplicity, echocardiography is not included. Distinct profiles are recognized for the main causes of respiratory distress: pneumonia, congestive heart failure, COPD, asthma, pulmonary embolism, and pneumothorax as summarized in Table 2.1. It has a diagnostic accuracy of > 90%.[40]

Table 2.1 BLUE protocol

P#	Profile name	Location	Appearance	Implication / diagnosis
1	A-profile	Anterior chest wall	. **lung sliding** – visualization of the movement of the visceral pleura against the parietal pleura with respiration . **A-lines**[(a)] – an indication of the presence of air below the parietal pleura	Normal lung surface
2	B-profile		. **lung sliding** . **lung rockets** – a pattern of three vertical B-lines[(b)] caused by edema in the inter-lobular septa.	Pulmonary edema
3	B'-profile		. **NO lung sliding** – in the B' profile lung sliding is abolished by the deposition of fibrin caused by pneumonia . **lung rockets**	Pneumonia
4	A/B-profile		. **unilateral lung rockets** – indicative for a (unilateral) pneumonia and does not correspond with generalized pulmonary edema	Pneumonia
5	C-profile	Anterior chest wall	. **anterior lung consolidation** – anteriorly located, therefore unlike to be caused by hemodynamic pulmonary edema or embolism.	Pneumonia
6	A-profile without DVT[(c)]		. **lung sliding** . **A-lines**[(a)] . **no DVT**	Normal
	A-no-V-PLAPS profile	Posterolateral chest wall	. **lung sliding** . **A-lines**[(a)] . **no DVT** . **PLAPS**[(d)] – posterolateral alveolar and/or pleural syndrome – pulmonary consolidation and pleural effusion	Pneumonia
7	A-profile with DVT[(c)]		. **lung sliding** . **A-lines**[(a)] . **DVT**	Pulmonary embolism
8	A'-profile	Anterior chest wall	. **NO lung sliding** – lung sliding abolished by separation of the visceral pleura from the parietal pleura . **A-lines**[(a)] – an indication of the presence of air below the parietal pleura	Pneumothorax when the mandatory 'lung point'[(e)] is visualized
9	A-profile without DVT and no PLAPS (nude profile)		. **lung sliding** . **A-lines**[(a)] . **no DVT** . **no PLAPS**	Asthma or COPD

This table is an adaptation of the work by Lichtenstein.[39]
The bedside lung ultrasound in emergency (BLUE) protocol defines nine profiles. They are defined by their sonographic appearance and are associated with the different diagnoses as described in the right-most column.

a. A-lines – horizontal repetition of the pleural line appearing below the pleural line at multiples of the skin-pleural line distance. Their appearance is an indication of air below the parietal pleura, either in or outside of the lung. They are particularly apparent in the absence of B-lines potentially obscuring the A-lines.
b. B-lines – a long, well-defined, hyperechoic comet-tail artifact arising from the pleural line that obliterates the A-lines.
c. DVT – deep venous thrombosis. Has to be separately found or excluded at the lower extremities
d. PLAPS – posterolateral alveolar and/or pleural syndrome (posterolateral consolidations or pleural effusions)
e. Lung point – the location where the visceral pleura is only partially in contact with the parietal pleura. With respirations, the A' profile (without lung rockets) is intermittently replaced with the A profile (lung rockets are possible). The lung point is a pathognomonic sign for the diagnosis of pneumothorax!
This is displayed in Video 2.1.

Video 2.1 Ultrasound video clip of the lung point

The part of the lung and visceral pleura that is still in contact with the parietal pleura is seen in the left side of the video clip. The right side of the clip shows the signs of a pneumothorax. The point where contact is lost, is called the lung point. With breathing, this point shifts back and forth.

Watch the video at https://www.reinketelaars.nl/video-2.1/

The LCI, triple scan, and BLUE protocol all might be relevant and valuable in the prehospital setting because of simplicity and nominal time investment. With the help of these protocols the EMS caregiver can accurately differentiate between causes to direct treatment and avoid unnecessary or harmful interventions.

Besides the diagnosis of dyspnea, lung US may be used to support prehospital continuous positive airway pressure (CPAP) treatment.[41]. In 20 ADHF patients, a physician-staffed EMS sonographically assessed 15 chest wall regions before and after CPAP treatment compared to standard treatment. The number of B-lines (explained in Table 2.1 and shown in Figure 2.1 and Figure 2.2) was significantly lower in the CPAP group, and their respiratory and hemodynamic variables improved after CPAP. The number of B-lines correlates with the amount of extravascular lung water (EVLW) and NT-proBNP levels and thus with the severity of ADHF. They develop at a pulmonary artery occlusion pressure (PAOP) > 18 mmHg.[42]

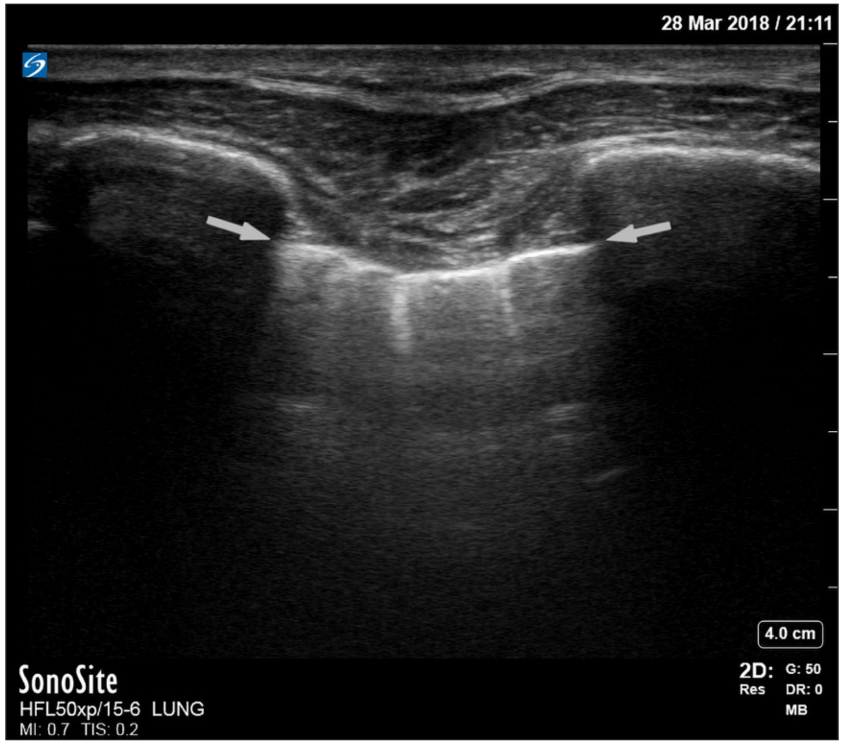

Figure 2.1 Normal lung

A normal lung ultrasound image acquired with a 15-6 MHz linear transducer. The ribs are visible with their anechoic shadows on both sides of the image. The pleural line is shown in between the ribs, indicated with two horizontal arrows. Emanating down from the pleural line are comet-tails. B-lines (not visible here) also start at the pleural line, but extend all the way down to edge of the image.

In high altitude medicine, Wimalasena described the value of lung US in the early detection of high altitude pulmonary edema (HAPE) before symptoms appear, and in differentiating HAPE from other causes of dyspnea such as pneumonia or pneumothorax.[43] The number of B-lines, indicating an increased amount of EVLW, is inversely correlated with the oxygen saturation and both values improve on (early) treatment.[44]

B – Chest, traumatic

- Pneumothorax

Using PoCUS for detecting pneumothorax is feasible, fast, without any radiation, has a steep learning curve and high diagnostic accuracy, and it allows for dynamic and repeated examinations.[45,46]

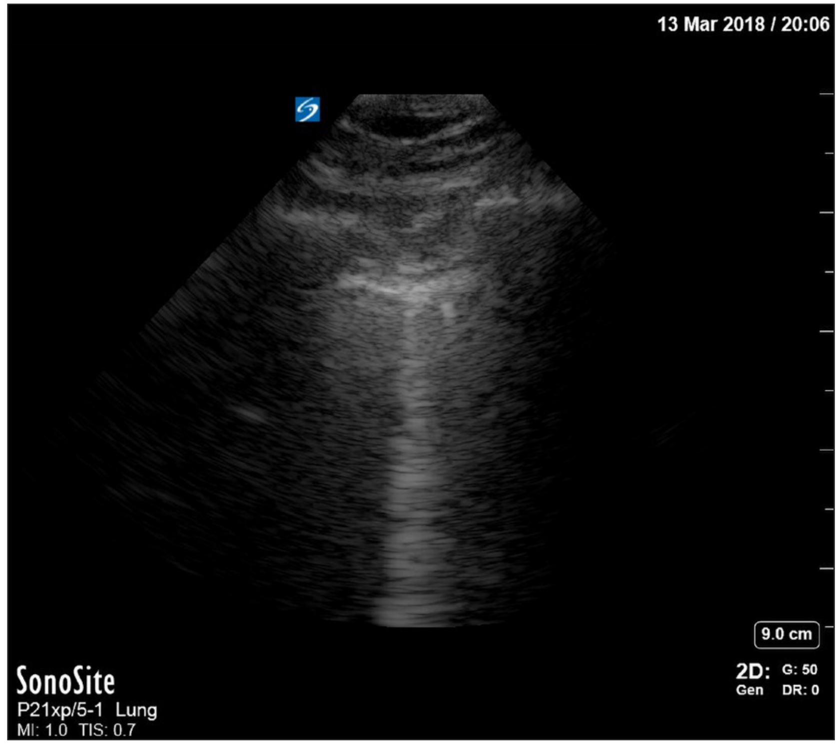

Figure 2.2 Normal lung + B-lines

A normal lung ultrasound image acquired with a 5-1 MHz phased array cardiac transducer. In the middle of the image one B-line is seen. This is also seen in healthy subjects and a single B-line is without meaning.

A pneumothorax is characterized by the abolition of lung sliding, the absence of B-lines and the appearance of the A-line sign.[39] Lung sliding is the representation of the visceral and parietal pleura sliding against each other during respiration. B-lines are the result of the accumulation of fluid in the pulmonary interstitium. Therefore, the presence of B-lines on PoCUS rules out a pneumothorax. Horizontal A-lines are reflections of the pleural line caused by gas below the parietal pleura either within or outside of the lung. These signs are explained further in Table 2 1; adapted from Lichtenstein's paper on the BLUE and FALLS protocol.[39] A normal lung US image is shown in Figure 2.1, Figure 2.2, and Figure 2.3. Images of pneumothorax are shown in Figure 2.4, Figure 2.5, and Video 2.1.

An important implication of detecting or excluding pneumothorax is the subsequent decision to perform (or withhold) a tube thoracostomy. An evaluation of prehospital chest US in 281 patients revealed that the acute medical management changed in 21%. The intention to introduce a tube thoracostomy was abandoned in 4% (n = 10) and the transport destination changed in another 4%.[4] Similarly, Mazur found that chest US examinations (n = 60) performed in preparation for air transport helped them prevent four (8%) chest tube thoracostomies.[47]

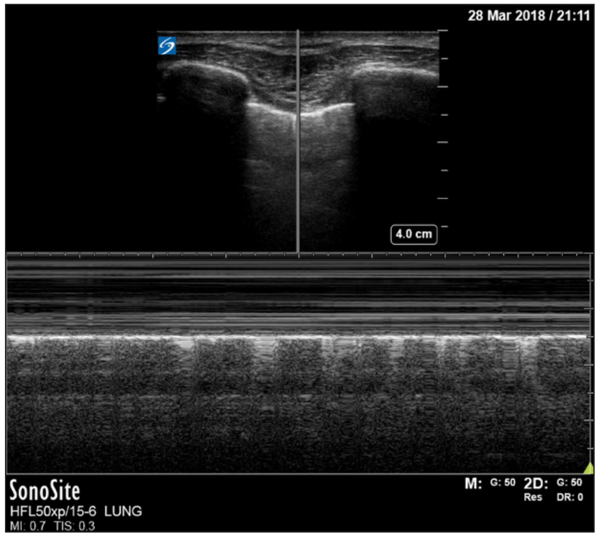

Figure 2.3 Normal lung – M-mode ultrasound image

The ultrasound reflections on the vertical line in the upper part of the image are sequentially displayed from left to right in the lower part as time progresses. It allows to capture the motion of the upper 2D image in the stationary image below.

A normal M-mode image of the chest wall and pleura is displayed here. The stationary chest wall produces straight horizontal lines above the pleural line. The lung sliding and movement of the artifacts below produces a grainy image. This is called the seashore sign.

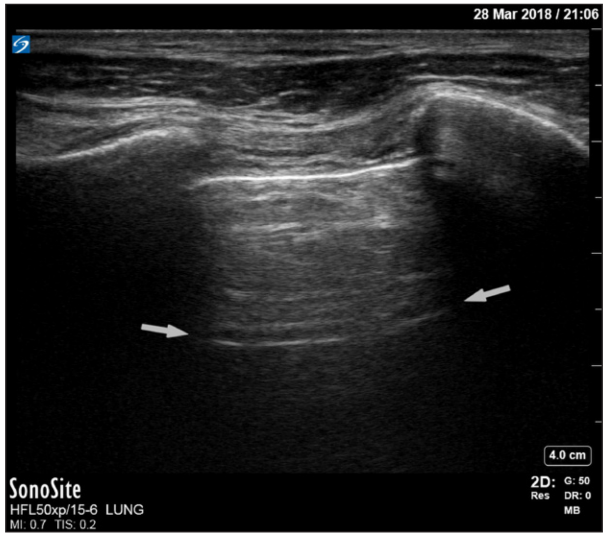

Figure 2.4 Pneumothorax + A-line

A-lines are reflections of the pleural line caused by gas below the parietal pleura. An A-line is indicated by the arrows. The A is for "air" either within or outside of the lung.

In case of a pneumothorax, there are no B-lines (Figure 2.2) that may obscure the A-lines making them stand out more clearly.

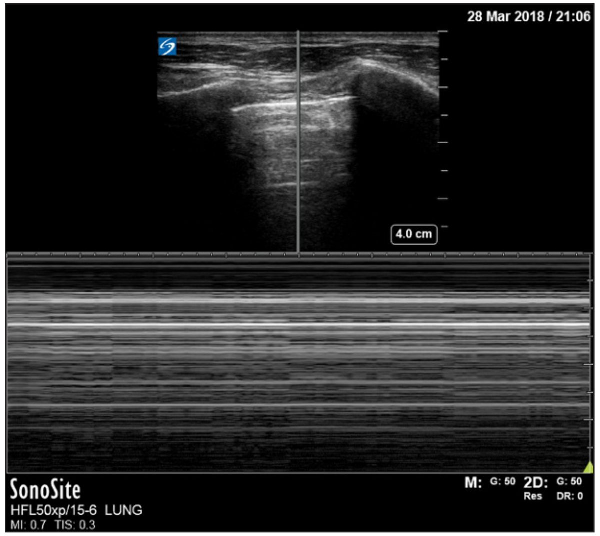

Figure 2.5 Pneumothorax – M-mode ultrasound image

There is no visible movement neither above nor below the pleural line. Because all tissue and artefacts are stationary, the M-mode image appears as horizontal straight lines throughout the image. This is called a barcode sign or stratosphere sign.

- Detection of pneumothorax during flight

In some EMS systems, patients are evaluated and treated while in-flight in a helicopter or fixed-wing aircraft. In prehospital and flight medicine, lung US was found to be feasible and safe.[16,24,48] For instance, M-mode (Figure 2 3 and Figure 2 5) ultrasonography was used to successfully evaluate a pleural interface model on board a helicopter while stationary, with rotor rotation before take-off, and at level flight.[49] Madill reported the case of a blast injury patient in whom an in-flight chest US examination identified an untreated pneumothorax. This directed the decision to perform a successful in-flight thoracentesis and tube thoracostomy.[50] In 2013, Roline reported to be the first to evaluate in-flight chest US in a helicopter emergency medical service (HEMS) operation.[51] They performed 41 chest US examinations in 71 patients. Expert sonographers reviewed the images and reached substantial agreement with the providers. Image quality was good or poor in 54% and 46%, respectively. Challenges consisted of the lack of time, limited aircraft space, and, less frequently, the presence of pacer pads. They concluded that in-flight chest US is feasible, has a steep learning curve, and that additional training is needed to improve image quality. Quick et al. found that the diagnostic accuracy of in-flight US for pneumothorax is nearly similar to US in the ED: 91% and 96%, respectively.[52]

These reports suggest that PHUS augment the diagnostic capabilities of prehospital aeromedical providers, also when in-flight, and might lead to better outcomes.

- Hemothorax

No studies with substantial data on the diagnostic performance of PHUS and hemothorax are available. Ketelaars described that PHUS detected one hemothorax in seven cases specifically assessed for hemothorax with 100% accuracy.[4] In a 2007 best evidence topic report the authors concluded that ultrasound is a sensitive, specific, and accurate method to detect the presence of hemothorax in trauma patients.[53] A more recent meta-analysis of hospital studies revealed a pooled sensitivity and specificity of 67% and 99% of PoCUS for hemothorax. For radiography, these were 54% and 99%.[54] Therefore, PoCUS for hemothorax may be valuable in both in-hospital and prehospital settings. Future studies might demonstrate the added value of early, prehospital, detection of hemothorax although an early chest tube thoracostomy is rarely required.[55] Still, PHUS yields valuable information to include in the prearrival notification to the receiving trauma center.

- Diaphragmatic rupture

Diaphragmatic rupture occurs in up to 5% of blunt abdominal trauma patients and may be present despite a negative FAST scan.[56] Ultrasonographic signs may be poor movement (on M-mode) or elevation of the diaphragm, a liver sliding sign (at the right chest wall), subphrenic effusion, or the presence of an intrathoracic spleen or liver.[57–59] In addition, Gangahar introduced Rip's absent organ sign as an indirect marker: nonvisualization of the spleen or heart caused by displacement of abdominal contents anteriorly to these organs.[60,61]

B – Gastric tube

The only indication for a gastric tube (GT) in the prehospital setting is to relieve gastric distention that is often caused or aggravated by bag-valve-mask ventilation. Traditionally, correct positioning is verified by injecting air in the tube while listening for air bubbles, or by aspiration of gastric contents. These methods are unreliable, especially in the noisy prehospital environment, and the recommended pH measurements and chest X-rays are not feasible.[62] Chenaitia et al. estimated the diagnostic accuracy of PHUS confirming GT placement in 130 prehospital intubated patients, compared to in-hospital chest X-ray. They positioned the probe subxiphoidal in the transverse plane, oriented towards the left hypochondrium to visualize the GT tip in the gastric antrum. Examination time was limited to 1 minute. Sensitivity and specificity were 98.3% and 100%. PPV and NPV were 100% and 85.7%.[63]

In a follow-up study they added an esophageal view at the anterior neck during and after GT insertion. In case the GT was visualized in the esophagus but not in the stomach 50ml of air was inserted. An intragastric position of the tip was visualized or assumed when gastric air entry was observed as dynamic fogging: an expanding volume of hyperechoic 'fog'. Sensitivity and specificity were both 100% compared to in-hospital chest X-ray.[64] When US is only performed after GT insertion, it is as fast as the traditional air insufflation and aspiration method.

C – Circulation – cardiac arrest

Current European resuscitation guidelines state that there is no doubt that focused cardiac ultrasound (FoCUS)—using specific protocols for US evaluation—has the potential to detect reversible causes of cardiac arrest.[12] FoCUS can help distinguish the PEA type, identify the cause of the arrest, choose a suitable treatment, and make the right decision on cardiopulmonary resuscitation (CPR) termination.[65] In 75% of the patients with pulseless electrical activity (PEA) FoCUS showed coordinated cardiac motion (pseudo-PEA) in a prehospital peri-resuscitation care study.[66] Pseudo-PEA is strongly associated with increased survival compared to a true PEA. Treatable causes were reduced ventricular function (59%), pericardial tamponade (9.8%), a significantly dilated right ventricle (7.8%), and hypovolemia (3.9%).[66] A return of spontaneous circulation (ROSC) was indeed achieved after pericardiocentesis. Three of five tamponade patients survived to hospital admission.

Similarly, cardiac motion in PEA patients in the ED is positively associated with ROSC. Salen found that in eight of 11 (73%) patients with sonographic cardiac activity ROSC was achieved but in none of 23 without cardiac activity.[67] A retrospective analysis of 318 pulseless trauma patients revealed that the survival of pulseless traumatic arrest patients without sonographic cardiac activity is rare.[68] In non-trauma ED patients, cardiac standstill on FoCUS during CPR correlated with death with a PPV of 97.1% and an NPV of 57.1%.[69] However, the timing and the duration of the FoCUS examination could be very important.

Termination of resuscitation (TOR) may be considered in out-of-hospital cardiac arrest patients when these four criteria are met: no ROSC before transport, no shock delivered, no bystander CPR, and an unwitnessed arrest.[70] Goto developed a similar TOR rule: no prehospital ROSC, nonshockable initial rhythm, and unwitnessed by bystanders. Their rule is a > 99% predictor of death within one month after out-of-hospital cardiac arrest (OHCA).[71] Cardiac standstill on initial FoCUS may predict non-ROSC and could be used in the decision for the termination of treatment.[67,72] However, a 2016 study in non-traumatic OHCA patients undergoing serial FoCUS confirmed ROSC could occur within ten minutes after initial cardiac standstill.[73] However, after a cardiac standstill of ten minutes or longer no ROSC occurred. These findings suggest that PHUS might play an important role here: consider TOR after ten minutes of sonographic cardiac standstill?

In addition to uncovering treatable causes of cardiac arrest, FoCUS is invaluable confirming mechanical ventricular capture (as opposed to electrical capture) during transcutaneous cardiac pacing.[74]

C – Shock

Although the cause of shock may not be apparent, FoCUS might guide therapy such as intravenous fluid administration, inotropic therapy, and the choice of destination hospital. FoCUS directly altered treatment in 51% of the cardiac arrest and peri-resuscitation patients in Breitkreutz's prehospital study.[66] This implies that every hemodynamically unstable patient could potentially benefit from PHUS.

- non-traumatic shock

To evaluate critically ill patients with acute circulatory failure, Lichtenstein devised the fluid administration limited by lung sonography (FALLS)-protocol aimed at reducing the mortality from septic shock.[39] It aims to sequentially rule out (1) obstructive, (2) cardiogenic, and (3) hypovolemic shock for expediting the diagnosis of distributive (usually septic) shock, displayed in Figure 2.6. When other causes of shock are eliminated and distributive shock (sepsis) remains, fluid therapy and vasopressors are indicated. Fluid therapy is guided by repeated chest ultrasound based on the appearance of the so-called B-profile as defined in the BLUE protocol (Table 2.1).

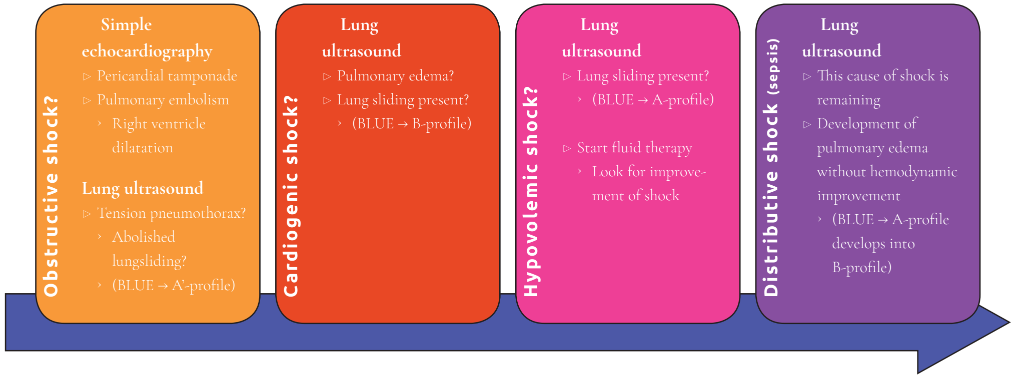

Figure 2.6 FALLS protocol

This diagram is an adaptation of the work by dr. Lichtenstein.[39]

FALLS protocol. Firstly, this diagram shows the type of shock the focus is on. Secondly, the type of ultrasound examination is shown. Thirdly, possible diagnoses to consider are shown including their appearance in terms of the BLUE protocol. Every cause of shock is sequentially excluded for expediting the diagnosis of distributive (septic) shock.

FALLS, fluid administration limited by lung sonography; BLUE, bedside lung ultrasound in emergency; BLUE and the A, B, and A'-profile are explained in Table 2.1: item 1, 2, and 8, respectively.

The rapid ultrasound in shock (RUSH) examination involves a three-part assessment simplified as (1) the pump, (2) the tank, and (3) the pipes.[75] The pump refers to an evaluation of the pericardial sac, left ventricular contractility and the relative size of the right ventricle to the left ventricle. The tank refers to the determination of effective intravascular volume status by measuring the inferior vena cava (IVC) and assessment of the lung, pleural and abdominal cavity. The pipes refer to scanning for an aneurysm or dissection of the thoracic and abdominal aorta, and deep venous thrombosis.

Both the FALLS and RUSH protocol combine familiar US scans proven to be feasible in the prehospital setting. Although we are unaware of any reports, these protocols are potentially valuable in prehospital care.

- traumatic shock

In traumatic shock, the (extended) FAST protocol may be used to detect a hemoperitoneum. A US image of a normal hepatorenal recess and one with a hemoperitoneum are displayed in Figure 2.7 and Figure 2.8. In abdominal trauma, its sensitivity and specificity are comparable between in-hospital and prehospital: 100% and 97.5% in-hospital and 90% and 99% prehospital, respectively.[2] The feasibility and efficiency of the extended FAST were also comparable, with no significant difference in US duration.[22]

In shocked blunt abdominal trauma patients, expeditious PoCUS should take a minimum amount of time. Clarke found that mortality increases by 1% for every three-minute delay of a necessary intervention.[76,77] Unfortunately, false-negative results do occur and they do most frequently in scans performed early in the disease process.[22,78] Therefore, when FAST

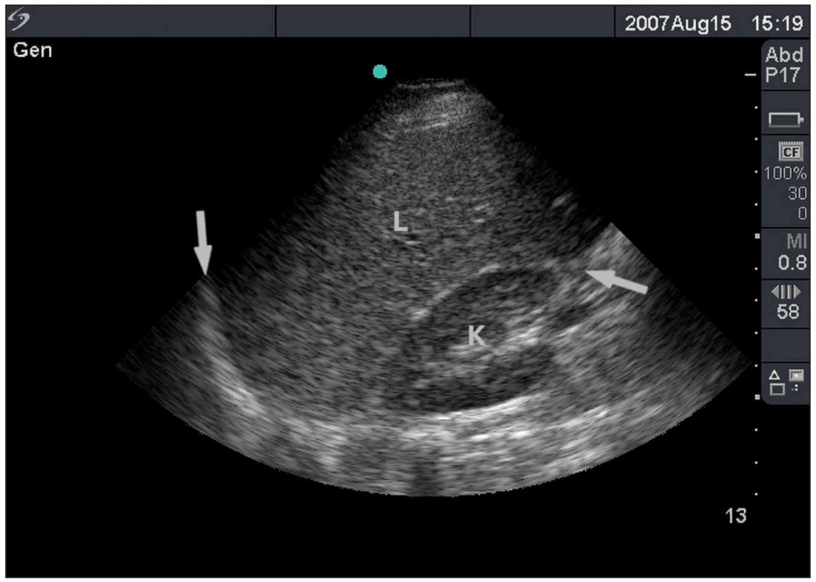

Figure 2.7 Normal hepatorenal recess

A normal ultrasound image of the hepatorenal recess (Morison's pouch). A phased-array cardiac transducer was used with the abdominal settings. The left arrow indicates the diaphragm. The right arrow indicates the hepatorenal recess. The liver (L) is shown above this line and the right kidney (K) below.

is negative it is recommended to repeat the examination every 15 minutes.[2,77] Repeated abdominal US scans may lead to a 50% reduction of false negatives.[79] However, a hemorrhage in the retroperitoneum or any solid organ injuries cannot be detected reliably with FAST. So, a negative FAST does not compensate a high suspicion of abdominal hemorrhage.

A (non) traumatic pneumoperitoneum is almost invariably caused by gastrointestinal perforation. When detected prehospitally this might steer early treatment and transportation. Sensitivity and specificity of abdominal US for pneumoperitoneum is 85–90% and 100%. In experienced hands it can be as good as CT; an amount as small as 1 ml of free air can be detected.[80–82] Thus, it appears plausible to use PHUS also for this indication.

In their meta-analysis, Stengel et al. concluded that US for blunt abdominal trauma does not decrease the laparotomy rate or mortality. Nevertheless, the number of ordered CT scans decreased by 50%. However, this might reflect a false sense of security due to the low sensitivity of abdominal ultrasound for both free fluid and organ lacerations.[7] Montoya also reported that US led to fewer CT scans. In addition, however, they found a decreased time to appropriate interventions, shortened hospital stay, and decreased use of healthcare resources.[78]

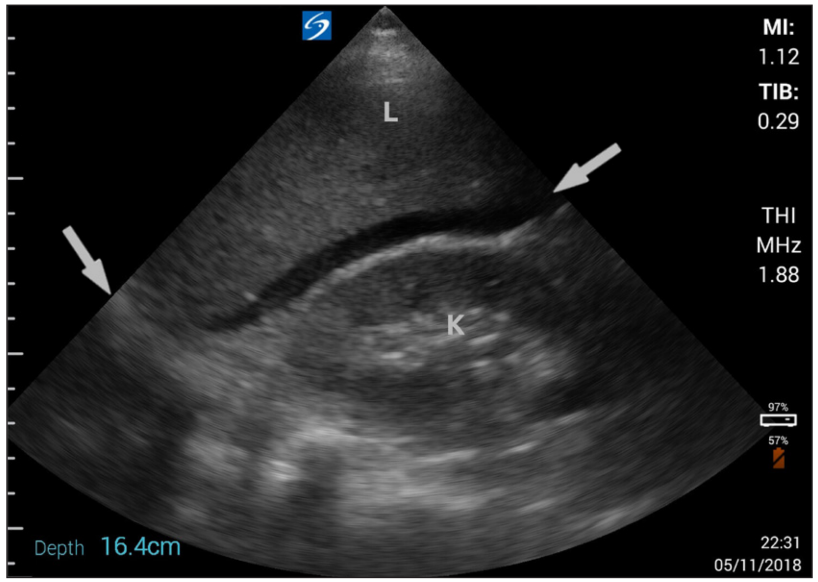

Figure 2.8 Hemoperitoneum at the hepatorenal recess

An ultrasound image of the hepatorenal recess (Morison's pouch). A phased-array cardiac transducer was used with the abdominal settings. The left arrow indicates the diaphragm. The right arrow indicates the hepatorenal recess with a hypoechoic collection between the liver (L) and the right kidney (K). This is the image of free intraperitoneal fluid and is very suggestive for intraperitoneal hemorrhage when encountered in a trauma victim.

C – Abdominal aortic aneurysm

US is feasible and suitable to assess for an aneurysm of the abdominal aorta in symptomatic patients. An ED study showed a sensitivity and specificity of 100% and 98%.[83] Prehospitally this is also feasible, reported Heegaard et al. Trained ambulance paramedics performed PHUS scans of the abdominal aorta in twenty symptomatic patients. A blinded expert also judged the images and agreed in 100% with the paramedics' judgment.[84]

D – Central nervous system

- Stroke – transcranial US

Reducing the interval between ischemic stroke and intravenous thrombolysis is associated with reduced mortality, reduced symptomatic intracranial hemorrhage, and higher rates of independent ambulation at discharge and discharge to home.[85,86] Unfortunately, prehospital delays lead to missed opportunities to initiate treatment within the preferred 90 minutes after the onset of symptoms.[87] For instance, in an American study, only 38% of patients arrived within two hours of the onset of their symptoms.[88]

Early prehospital detection of ischemic stroke may be beneficial to a favorable outcome. Prehospital caregivers could allocate patients to the most appropriate hospital, provide a prearrival notification, and initiate stroke-specific therapies such as sonothrombolysis and neuroprotective strategies.[87,89,90] Intravenous thrombolysis, however, is only administered safely after a CT or magnetic resonance imaging (MRI) scan excludes an intracranial hemorrhage.

Herzberg et al. evaluated the diagnostic accuracy of prehospital neurological examination supported by transcranial color-coded sonography (TCCS).[89] The TCCS consisted of color-mode visualization and flow measurements in the proximal M-1 segment of both middle cerebral arteries (MCA) to find an occlusion. When desired, they scanned the anterior and posterior cerebral arteries or administered an intravenous ultrasound contrast agent (UCA). Sensitivity and specificity were 95% and 48%; PPV and NPV were 82% and 77% for the prehospital diagnosis of 'any stroke' compared to in-hospital CT angiography (CTA) and magnetic resonance angiography (MRA). With appropriate training, telemedicine, and UCAs, these results might still improve.[89]

In their prehospital study, Schlachetzki found that 36% of the physicians used microbubbles as a UCA to save time or to increase the diagnostic confidence when temporal window anatomy did not allow an optimal visualization of the MCAs. Sensitivity and specificity of ultrasound for MCA occlusions were 90% and 98%. PPV and NPV were 90% and 98%.[90]

Besides arterial occlusions, vasospasm due to aneurysmal subarachnoid hemorrhage may be detected by transcranial US. However, its diagnostic accuracy varies widely depending on the vessel, the diagnostic criteria and timing.[91] Anecdotal evidence exists on other intracranial pathologies which may be detected by PHUS such as intracranial hematomas and ventricular system enlargement.[92,93]

The biggest limitation of the application of transcranial US is the ability to obtain US images through the temporal window (Figure 2.9). This is the thinnest part of the temporal bone that allows penetration of the US beam at a suitable angle and distance in relation to basal portions of the major cerebral arteries and the circle of Willis. This procedure may be very demanding and requires training and experience. Therefore, transcranial US might not be suitable for every ultrasound-equipped (H)EMS service.

The therapeutic applications of transcranial US in ischemic stroke are discussed in the interventions section of this paper.

Figure 2.9 Ultrasound transducer positioned at the temporal window

The ultrasound transducer is positioned at the site where the temporal bone is thinnest and the ultrasound beam is least obstructed penetrating the skull.

Reproduced with permission. Image courtesy of Rob Stoffels and Yvonne Houben.

ONSD

Both optic disc edema detected by fundoscopy and an increased optic nerve sheath diameter (ONSD) are indications of increased intracranial pressure (ICP).[94] The ONSD can easily be measured using US, although the use of a UCA might enhance the recognition of relevant anatomy.[95] ONSD measurements, using a cut-off value of 5.0 mm, have a sensitivity and specificity of 100% and 95% in predicting an elevated ICP compared to CT.[96] Moretti et al. compared US to invasive ICP measurements. Using a cut-off value of 5.2 mm they found a sensitivity and specificity of 93.1% and 73.9% for an ICP ≥ 20 mmHg.[97] More recently, Maissan et al. measured the ONSD in ICP-monitored traumatic brain injury (TBI) patients before, during, and after routine suctioning of the endotracheal tube leading to a transient ICP rise. With a cut-off value of 5.0 mm they found the sensitivity and specificity to be 94% and 98% for a rise in ICP.[98]

Like US in ischemic stroke, the benefit of prehospital ONSD measurements might be to start neuroprotective strategies, to determine the need for neurosurgical care, or to provide a prearrival notification. However, the evidence on prehospital feasibility and benefit is still negligible.

E – Injuries

Fractures

Dulchavsky concluded that non-physicians in the ED (cast technicians) can reliably diagnose orthopedic injury with an accuracy of 94% after a brief PoCUS training. This was more reliable for fractures of the humerus, forearm, femur, and lower leg than for hand and foot fractures, and tendon injuries.[99]

Bozorgi et al. evaluated US in 108 ED patients with 158 fractures in the extremities. Overall sensitivity was 68.3%. Sensitivity for femoral fractures and humeral fractures was 100% and 76.2%, respectively. The detection of intra-articular fractures was the most difficult with a sensitivity of only 48%.[100]

In the civilian prehospital setting, PHUS for fractures is probably feasible. It is useful for (long) bone fractures in the upper and lower arm, and leg. Advantages in the prehospital setting could be early reduction and splinting, triage, selecting the best destination provided with a specific prearrival notification.

Foreign objects

In the wilderness environment, Paziana described two cases where PHUS was successfully used to aide in the removal of foreign objects from soft tissue.[101] PHUS may determine the exact location and depth of a foreign object despite that some are radiolucent. The location and size of the incision can be determined, and the removal may take place under direct US visualization.

Ocular ultrasonography

Besides ONSD measurements, ocular US appears useful and feasible in the prehospital setting. It is useful to diagnose penetrating globe injury, foreign body retention, retinal detachment, vitreous detachment, central retinal artery occlusion, lens dislocation, retrobulbar hematoma, and retinal and vitreous hemorrhage.[102,103] The eye can be accurately assessed without the need to open the eyelid in case of swelling. An austere environment case report described PHUS helping to diagnose a retinal detachment after a facial gunshot wound. Immediate evacuation was arranged to facilitate appropriate follow-up care.[104]

Interventions

Hereabove, many diagnostic applications of PHUS have been discussed. Besides its diagnostic applications, PHUS has been shown to be potentially valuable guiding interventions or as a therapeutic intervention in its own right.

Interventions – Airway

Emergency percutaneous cricothyrotomy may be unsuccessful or produce a tear in the posterior tracheal wall. Siddiqui et al. compared anatomical orientation by either digital palpation or US for performing a percutaneous cricothyrotomy with the Portex® device. In cadavers in which palpation of the cricothyroid ligament is difficult, US increased the probability of a correct device insertion by 5.6 times and reduced the incidence of laryngeal and tracheal injury from 100% to 33%. A possible disadvantage of US may be the prolonged time to airway insertion.[105]

In the emergency prehospital setting the open cricothyroidotomy is the preferred approach in invasive airway management. Whether a US-guided percutaneous technique should be used in an emergency at all, is a matter of debate. Nevertheless, Curtis et al. found a US-guided bougie-assisted open cricothyroidotomy to be a rapid and reliable technique. Cricothyroidotomy was successful in 20 of 21 cadavers, with a median time to completion of 26.2 s.[106]

Interventions – Breathing

Medical patients with severe symptomatic pleural effusion might require early pleural aspiration in the prehospital setting. Pleural US is useful in the diagnosis and localization of fluid. US-guided thoracentesis is a safer and more effective method to relieve symptoms than a blind approach.[107,108]

Interventions - Circulation

To guide interventions, PHUS is most frequently used for (central) venous access. It was the second most used PHUS application overall (after assessment of blunt abdominal trauma) in an Australian retrieval team.[47] Intraosseous access is the most appropriate approach in time-critical emergencies. However, for less urgent but difficult to obtain peripheral intravenous access, US-guidance is faster and more effective than traditional catheter insertion.[109]

Symptomatic pericardial effusion might need prompt treatment in the prehospital setting.

US-guided pericardiocentesis under continuous visualization using a multi-angled needle guide was found to be effective, safe, and easy to perform.[110]

First described in 1954, resuscitative endovascular balloon occlusion of the aorta (REBOA) is a technique to stabilize patients suffering hemodynamic shock by temporarily interrupting blood flow to non-compressible hemorrhage in the chest, abdomen, or pelvis.[111,112] In animal studies, REBOA resulted in a 74% mortality risk reduction.[113] After forty minutes of occlusion, however, the risks start outweighing the benefits.[113,114] In 2014, the London HEMS was the first to report a prehospital performed REBOA in a patient with a pelvic fracture resulting in successful hemorrhage control.[115]

Chaudery found that the use of US improved the correct placement of REBOA catheters, shortened the time until correct placement, and improved the participants' confidence in catheter placement of Zone III (infrarenal aorta) REBOA catheters in 20 porcine cadavers.[116]

These developments are promising for future prehospital US-guided REBOA hemorrhage control. However, future research is needed on prehospital feasibility, variations in body habitus, and zone I (intrathoracic aorta) placement.

Interventions - Disability

In the aforementioned disability section we highlighted the value of TCCS in diagnosing ischemic stroke. A therapeutic application of ultrasound in ischemic stroke patients is continuous transcranial doppler (TCD) to enhance the thrombolytic activity of tissue plasminogen activator (t-PA).[117] In a phase II multicenter randomized trial (CLOTBUST) transducers were applied over the temporal bone in a head frame. The investigators applied TCD (or placebo TCD) on maximum power output continuously for two hours and simultaneously started intravenous t-PA treatment in all patients. Two hours after starting thrombolysis recanalization or almost full recovery was observed in 49% in the continuous TCD group versus 30% in the control group. However, clinical recovery after 24 hours and outcome after three months was similar.[117] In 2014, another analysis of the CLOTBUST trial, including more subjects, revealed 38.6% complete recanalization in the sonothrombolysis group and 17.1% in the intravenous t-PA group.[118] A phase III trial is underway.[119] Tsivgoulis concluded in a meta-analysis that high-frequency ultrasound (both TCD and TCCS) combined with t-PA was associated with a higher likelihood of complete recanalization (pooled OR = 2.99) than t-PA alone.[120] They found no increased risk of symptomatic intracerebral hemorrhage.

Probably, transcranial US combined with microbubbles but without t-PA is effective as well.[121,122] Microbubbles consist of an injectable aqueous suspension of small (1.5–4.7 μm) bubbles of a high molecular-weight gas that is used as a US contrast agent to improve the visualization of blood vessels.[123] In a meta-analysis, Saqqur indeed concluded that sonothrombolysis with or without microbubbles or t-PA was effective and safe.[124] These findings allow the exploration of early prehospital initiation of sonothrombolysis in suspected ischemic stroke without needing a CT or MRI scan. Hölscher already suggested that PHUS could serve to 'precondition' the culprit clot to increase its therapeutic sensitivity to t-PA or neurointervention while providing neuroprotection for tissue at risk.[121]

Interventions – Regional anesthesia

US-guided regional anesthesia is a common technique for providing perioperative pain relief for elective surgical procedures of the extremities. These techniques can also be employed in the prehospital setting to provide effective analgesia for extremity injuries and avoiding the side-effects associated with the administration of systemic analgesics. For instance, ultrasound-guided femoral nerve blocks effectively provide pain relief in hip fractures.[125] Also, PHUS might facilitate already successful prehospital fascia iliaca compartment blocks.[126] Similarly, Lippert et al. suggested the added value of US-guided nerve blocks to improve pain control in disaster settings.[127]

The transversus abdominis plane (TAP) block is an effective technique for pain relief in pelvic fractures and because of its ease and safety it may be applicable in the prehospital setting.[128] Blocking the nerves that supply the anterior abdominal wall relaxes the abdominal wall muscles that will subsequently reduce the traction on the ischium and pubis. The 'flank bulge sign' is a direct consequence of this relaxation.[129]

Disaster triage

In a multiple casualty incident (MCI), resources are limited. Triage systems are used to determine treatment priority of the injured patients based on history and physical examination. PoCUS was reported to be valuable in the triage process during several earthquake disasters.[130–134] Stawicki proposed a protocol that integrates some common PoCUS applications to evaluate the chest, abdomen, vena cava, and extremities as an adjunct to acute triage (CAVEAT) and to be executed during the secondary survey.[135] The protocol will take approximately five minutes longer than a traditional FAST scan. It is explained in more detail in Table 2.2. Although the merits of its component parts have been described extensively, the benefit of the protocol is yet to be established.

Table 2.2 The CAVEAT protocol

CAVEAT protocol				
Urgency	**Step**	**Examination**	**Focus on**	**Looking for**
Primary assessment (mandatory)	1	Evaluation of the pleura	Chest	Pneumothorax
	2	Complete FAST examination	Abdomen Costophrenic recesses	Hemoperitoneum Hemothorax
	3	Inferior Vena Cava assessment	Collapsibility index	Volume depletion
Secondary assessment (optional)	4	Upper- and lower extremities	Long bones; Regions of pain, tenderness, or deformity	Major fractures eligible for more accurate reduction and stabilization. Fractures to prioritize utilization of radiographic resources, or achieve even more accurate triage

CAVEAT, sonographic evaluation of the Chest, Abdomen, Vena cava, Extremities for Acute Triage.
FAST, Focused Assessment with Sonography for Trauma.
This table shows the suggested order of examinations in the CAVEAT protocol. Specific components may depend on the operators' skill level and on the individual patient's injuries.
This table is an adaptation of the work by dr. Stawicki.[135]

Future applications

Sonothrombolysis

As we have discussed in the interventions section, early prehospital sonothrombolysis in ischemic stroke patients might be safe and effective. The CLOTBUST investigators have developed a hands-free headframe containing 18 ultrasound transducers positioned at the temporal occipital bone windows to deliver operator-independent ultrasound energy directly to the culprit clot. It was successfully applied to and well tolerated by 15 volunteers and is currently evaluated in stroke patients.[136] It may facilitate and enhance early thrombolysis because of its portability and that no formal ultrasound training is needed.

Telemedicine

With improving data communication technologies, telemedicine is a promising technique for remotely evaluating ultrasound clips acquired by less-experienced operators. They might even be coached in real-time supported by remotely operating the ultrasound device settings in complex scenarios.[137] Kolbe introduced a PoCUS curriculum in a one-room medical clinic in rural Nicaragua. Despite limited resources, after the first introduction the ultrasound instructors used telemedicine to remotely view the ultrasound images in real-time.[138] In 2016, Kirkpatrick demonstrated the feasibility of remotely telementoring ultrasound-naïve fire-fighters using trauma ultrasound for free-fluid detection on a phantom.[137] Remote telementored ultrasound was feasible to coach untrained and inexperienced nurse practitioners to assess patients for pneumothorax immediately after removal of their tube thoracostomy.[139] Rubin demonstrated the feasibility of remote review and interpretation of TCD and carotid ultrasound data in healthy volunteers dubbed *teleneurosonology*.[140]

Integrating telemedicine concepts in PoCUS-enhanced disaster triage might be promising and feasible in the light of progressing technological advancements.

Wearable US

Mierzwa developed a flat and flexible 5 MHz US probe designed to wear on a fingertip to aid in US-guided vascular access, for instance. The device can be configured as a linear or curvilinear transducer array and it can be mounted directly onto the body as an adhesive patch or wearable device. They speculate on many applications such as point-of-care imaging, combat casualty care, ultrasound therapy, and patient monitoring.[141] A specific prehospital application might also be a US patch for continuous cardiac visualization during cardiopulmonary

resuscitation.

Assessment of intraosseous needle position

Tsung demonstrated the feasibility of US to determine the location of an intraosseous needle in six resuscitation cases. He argues that every intraosseous access should be verified with color doppler because a correct position cannot be accurately confirmed by the aspiration of blood, blood on the stylet tip, the needle being firmly in place, or the absence of soft tissue extravasation.[142]

Predicting outcomes in resuscitative thoracotomy (RT)

In some countries, a prehospital or ED resuscitative thoracotomy (RT) is performed on patients with a penetrating (sometimes also blunt) thoracic injury decompensating into cardiac arrest. The goal is to treat a cardiac tamponade, major injuries of the heart, control intrathoracic bleeding, clamp the thoracic aorta, or perform direct cardiac massage or defibrillation. The RT is an invasive and last-resort treatment. Inaba found that FoCUS was a predictor of futile care in these patients.[143] In 187 RT patients only six survived and three were eligible organ donors. All survivors and organ donors had visible cardiac motion before RT was performed. If no cardiac motion or pericardial effusion on US was observed the survival was zero. Thus, utilizing US would have avoided a considerable number of RTs that were ultimately futile.[143] Because of these findings, PHUS would be a valuable addition to prehospital RT protocols.

US-guided cannulation for extracorporeal life support (ECLS)

Lamhaut concluded in 2013 that prehospital implementation of ECLS by non-surgeons was safe and feasible.[144] Four years later their group described a case of ECLS cannulation in the Louvre museum in Paris in which they used a hybrid surgical/Seldinger technique.[145,146] Another future PHUS application might be US-guided percutaneous ECLS cannulation that may be easier, faster, and less invasive. It could be complemented by (contrast enhanced) echocardiography to verify correct placement of the venous catheter tip.[147,148]

Challenges

PHUS is subject to specific challenges in the prehospital environment: ambient lighting, confined space, extremes of temperature, precipitation, dressings, splints, and rapid transport times.[3,6]

Diagnostic ultrasound is generally considered harmless. However, it may heat up tissue depending on these factors: exposure duration, the acoustic output, and tissue characteristics. For instance, some unique properties of the eye such as high absorption of ultrasound and the absence of cooling blood supply may cause the lens to heat up faster than other tissues.[149,150] Therefore, this has to be considered in ocular ultrasound or ONSD measurements.

PHUS is used by nonradiologists mainly to answer simple yes/no questions and to guide treatment decisions. Sensitivity for solid organ injuries is low and small quantities of blood early in the post-injury phase may be missed. Traumatic aortic pathology cannot be detected by chest or abdominal US, therefore, PHUS is not a valid replacement for CT angiography in patients subjected to high-energy thoracic trauma.[78] False negatives will occur; therefore, negative findings should not indicate a final exclusion of diagnoses.[3] Thus, for some indications, the sensible choice might be to use PHUS only as a *rule-in* tool not to be falsely reassured by (false) negative test results.

Another concern of PHUS is the potential delay in treatment. In general, a slight delay might occur when PHUS is performed on-scene. However, delays are non-existent when performed in parallel with other procedures, while in-flight, or during ground ambulance transport. Busch found the median PHUS duration to be 2.5 min (range 1–3).[13] For a range of PHUS examinations, Hoyer measured a mean of 1 min 54 s, decreasing to 56 s during the three-year study period.[3] In their review, Jørgensen et al. reported a delay of 0–6 minutes. Examination time depends on the protocol and the results: positive findings will reduce the examination time.[5]

Although a slight delay may occur, this might easily be outweighed by the advantage of improved diagnostic and therapeutic accuracy, and the potential time gains by transporting the patient directly to the most appropriate hospital.

Conclusions

We have provided a comprehensive summary of the literature on prehospital applications of diagnostic and therapeutic ultrasound structured according to the ABCDE approach. Also, we have highlighted in-hospital US procedures that appear useful and plausible for prehospital use, current challenges in PHUS, and potential future applications. It may be commendable to revise this review in the near future when, undoubtedly, additional useful PHUS applications will have emerged.

Improvements in portability, quality, and price of handheld ultrasound systems add to the accessibility and its feasibility for prehospital use. PHUS improves the diagnostic capabilities of prehospital health care providers and might improve treatment decisions, prearrival notifications, and transport mode and destination. As new PoCUS techniques and applications are being researched, new protocols are being tested for diagnostics, procedural guidance, and therapeutic use.

However, prehospital caregivers should unabatedly be aware of the limitations of PHUS. The time investment will not always pay off and diagnostic accuracy isn't perfect. Diagnostic accuracy is quite dependent on training and experience of the providers.

The diagnostic and therapeutic possibilities of PoCUS are increasing. With promising techniques, such as sonothrombolysis in ischemic stroke, we are bringing the hospital-level medical care to prehospital patients to an ever-increasing extent.[119]

Appendix A

Search strategy in the Ovid MEDLINE® database
1. emergency medical services/ or ambulances/ or air ambulances/
2. exp Aerospace Medicine/
3. exp Emergency Medicine/
4. exp Aviation/
5. exp Ultrasonography/
6. exp Obstetrics/
7. exp Intensive Care Units/
8. ambulance.ti. or ambulance.ab.
9. "out of hospital".ti. or "out of hospital".ab. or "out-of-hospital".ti. or "out-of-hospital".ab.
10. helicopter.ti. or helicopter.ab.
11. prehospital.ti. or prehospital.ab.
12. pre-hospital.ti. or pre-hospital.ab.
13. aeromedical.ti. or aeromedical.ab.
14. "emergency care".ti. or "emergency care".ab.
15. "emergency medical service*".ti. or "emergency medical service*".ab.
16. air medical transport*.ti. or air medical transport*.ab.
17. aerospace medicine.ti. or aerospace medicine.ab.
18. ultraso*.ti. or ultraso*.ab.
19. sonograph*.ti. or sonograph*.ab.
20. echocardiograph*.ti. or echocardiograph*.ab.
21. echogra*.ti. or echogra*.ab.
22. portable ultraso*.ti. or portable ultraso*.ab.
23. psychiatr*.ti. or psychiatr*.ab.
24. intensive care unit*.ti. or intensive care unit*.ab.
25. ICU.ti. or ICU.ab.
26. battlefield.ti. or battlefield.ab. or military.ti. or military.ab. or combat.ti. or combat.ab.
27. exp Military Medicine/
28. austere.ti. or austere.ab.
29. 1 or 2 or 3 or 4 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 26 or 27 or 28
30. 5 or 18 or 19 or 20 or 21 or 22
31. 6 or 7 or 23 or 24 or 25
32. (29 and 30) not 31
33. limit 32 to (dutch or english or german)

This search was conducted on 21 August 2017 and produced 2315 hits.

2

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Chapter 3

Which ultrasound transducer type is best for diagnosing pneumothorax?

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Abstract

Background

An accurate physical examination is essential in the care of critically ill and injured patients. However, to diagnose or exclude a pneumothorax, chest auscultation is unreliable compared to lung ultrasonography. In the dynamic prehospital environment, it is desirable to have the best possible ultrasound transducer readily available. The objective is to assess the difference between a linear-array, curved-array, and phased-array ultrasound transducer in the assessment for pneumothorax and to determine which is best.

Methods

In this double-blinded, cross-sectional, observational study, fifteen observers, experienced in lung ultrasonography, each assessed 66 blinded ultrasound video clips of either normal ventilation or pneumothorax that were recorded with three types of ultrasound transducers. The clips were recorded in 11 adult patients that underwent thoracoscopic lung surgery immediately before and after the surgeon opened the thorax. The diagnostic accuracy of the three transducers, elapsed time until a diagnosis was made, and the perceived image quality were recorded.

Results

In total, fifteen observers assessed 990 ultrasound video clips. The overall sensitivity and specificity were 98.2% and 97.2%, relatively. No significant difference was found in the diagnostic performance between transducers. A diagnosis was made slightly faster in the linear-array transducer clips, compared to the phased-array transducer ($p = .031$). For the linear-, curved-, and phased-array transducer, the image quality was rated at a median (interquartile range [IQR]) of 4 (IQR 3–4), 3 (IQR 2–4), and 2 (IQR 1–2), relatively. Between the transducers, the difference in image quality was significant ($p < .0001$).

Conclusions

There was no difference in diagnostic performance of the three transducers. Based on image quality, the linear-array transducer might be preferred for (prehospital) lung ultrasonography for the diagnosis of pneumothorax.

Introduction

In the critically ill and injured patient, an accurate physical examination is essential in the care of the patient. However, auscultating for breath sounds in a respiratory distressed patient is often difficult or even impossible, especially in a noisy accident scene, or patient compartment of a (moving) ambulance or helicopter.

The sensitivity of auscultation for the diagnosis of hemothorax, hemopneumothorax, and pneumothorax is only 58–66%.[1–3] Unilateral decreased or absent breath sounds are often interpreted as a pneumothorax. However, conditions such as splinting from rib pain, lung contusion, atelectasis, pneumonia, pleural effusion, and tumor growth may account for the same abnormal auscultation.

Lung ultrasonography (US) for the diagnosis of pneumothorax was first described in 1986.[4] It may rule-in pneumothorax with a sensitivity ranging from 81–98% and rule it out with a specificity approaching 99–100%.[5–7] Additionally, pleural effusion, lung contusion, and atelectasis may be detected.[7] It has even been suggested that US might one day replace the stethoscope.[8,9]

US is feasible in the prehospital setting including inside ground ambulances and a helicopter emergency medical service (HEMS).[10–12] Similar to most diagnostic and therapeutic procedures, US requires training and regular practice. Time-pressure and limited working space are additional challenges.[12] To facilitate the best possible images, it is important that optimally set-up US equipment is readily available. In an optimal configuration, the most suitable transducer is connected to the US machine.

Lung US can be performed with either high-frequency linear-array, curved-array, or phased-array transducers. However, it is not known which one is preferable and provides the best images.

We hypothesized that a linear-array transducer is the optimal transducer for the appreciation of the pleural line for diagnosing pneumothorax. The aim of the study is to compare three transducer types on diagnostic accuracy, speed of the diagnosis, and image quality in the assessment for pneumothorax.

Methods

We performed a double-blinded, cross-sectional, observational study to compare three types of ultrasound transducers for the diagnosis of two conditions: normal ventilation, and pneumothorax. Ethical approval was obtained from the institutional ethics review board of the Radboud university medical center, Nijmegen. Written informed consent was asked and obtained from every patient and from every observer.

At the preoperative outpatient evaluation clinic of the Radboud university medical center, Nijmegen, the Netherlands, from September to October 2017, we recruited a consecutive series of eleven eligible patients that were scheduled for video-assisted thoracoscopic surgery (VATS) for pulmonary, mainly neoplastic, pathology. The inclusion criteria were a body mass index < 30 kg m^{-2} and the absence of pathology of the chest wall, visceral or parietal pleura.

Lung US is a valuable test for the detection or exclusion of a pneumothorax.[13,14] A US transducer is positioned on the chest wall perpendicular to two adjacent ribs. Between the acoustic shadows of two ribs, a hyperechoic line is visible representing the interface of the parietal and visceral pleura. With normal ventilation, lung sliding is observed as a to-and-fro movement at the pleural line as a result of the sliding of the visceral pleura against the inner chest wall. B-lines may be observed as hyperechoic lines radiating down from the pleural line. Their presence excludes pneumothorax (at the transducer position). Horizontal repetitions of the pleural line appearing below at multiples of the skin-pleural line distance are called A-lines. Their appearance is more prominent in the presence of a pneumothorax when B-lines are absent and no longer obscuring the A-lines.

We used a portable X-Porte ultrasound system (Fujifilm SonoSite Inc., Bothell, WA, USA) equipped with three transducers: a high-frequency linear-array 15–6 MHz (HFL50xp), a curved-array abdominal 5–2 MHz (C60xp) and a phased-array cardiac 5–1 MHz (P21xp) transducer. The footprints of the transducers are 5 cm, 6 cm, and 2.1 cm, respectively.

For the VATS procedure, isolated ventilation of the dependent lung via a double-lumen endotracheal tube was necessary. First, all patients underwent general anesthesia, were intubated and ventilated, and placed in a lateral decubitus position. The ventilator was set to deliver a tidal volume of 5 ml kg^{-1} at a rate of 20 min^{-1}. The anesthesiologist verified the position and depth of the double-lumen endotracheal tube with fiberoptic bronchoscopy.

Secondly, the linear array, curved-array, and phased-array transducer were positioned over the 4th or 5th intercostal space at the axillary line in a cranio-caudal orientation. 15-second ultrasound video clips were recorded of normal ventilation at a respiratory rate of 20 min^{-1}. The zone of interest was the pleural line with its two adjacent ribs. A typical clip was framed as shown in Figure 3.1.

Figure 3.1 Typical uncropped image of the pleural interface acquired with a linear-array transducer

Thirdly, after the chest was prepped and draped, ventilation of the non-dependent lung was interrupted while the surgeon opened the chest, introduced the videoscope and visually confirmed the collapse of the lung. Thereafter, the surgeon recorded three similar 15-second video clips of the established pneumothorax with the three transducers wrapped in sterile transducer covers (Figure 3.2). Hence, six clips were recorded in every patient. The time interval between the induction of the pneumothorax (reference test) and the performance of the three ultrasound video clips was no longer than two minutes. No adverse events occurred.

We cropped the video clips using iMovie for OS X, version 10.1.8 (Apple Inc., Cupertino, CA, USA). After we cropped and removed the text from the captured video clips, it was now no longer possible for the observers and the researchers to reliably recognize the transducer type by the image shape (rectangular or sector-shaped). An uncropped still image of the video clip and its cropped version are displayed in Figure 3.3.

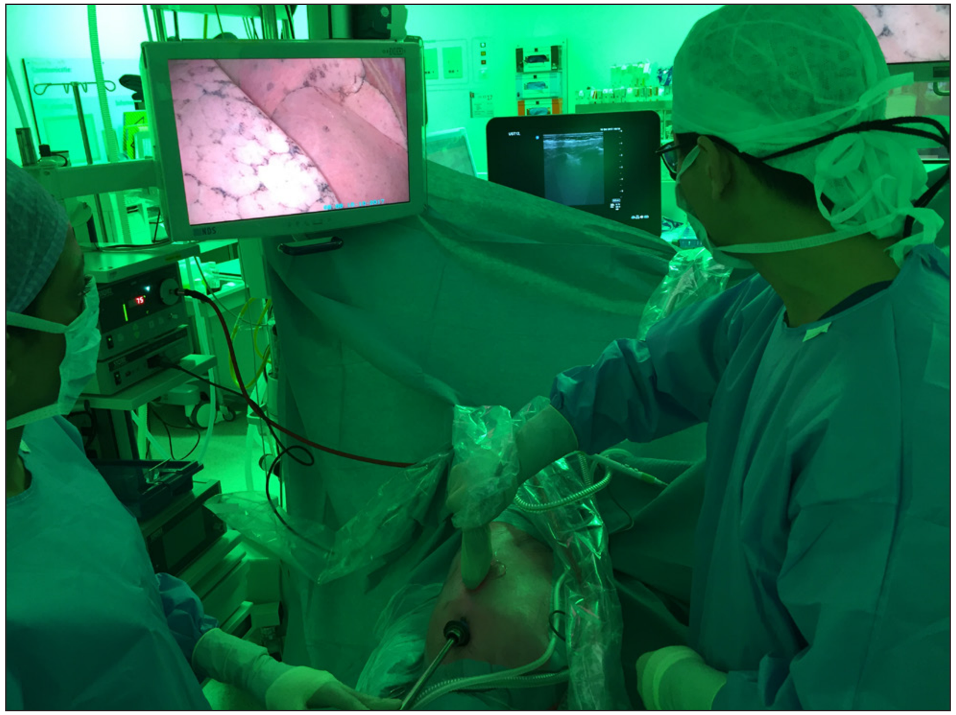

Figure 3.2 The surgeon performs lung ultrasonography in a patient with a confirmed pneumothorax and the videoscope in situ

The video screen displays an image of the inside of the right hemi-thorax and the collapsed right lung. The surgeon is handling the wrapped-up ultrasound transducer. The ultrasound device is shown in the back of the image.

The Nijmegen physician-staffed HEMS carries a portable US machine since 2006. All HEMS physicians were trained in lung US either at the introduction of the US machine or at the start of their employment. They use lung US regularly in their prehospital practice.

We recruited all 13 HEMS physicians (except the author, RK) and two anesthesiology residents with extensive experience in lung ultrasonography as observers to assess a randomized set of 66 15-second ultrasound clips. We used PotPlayer for Windows, version 1.7 (Kakao Corp., Jeju, South Korea) to separately randomize and playback the cropped set of clips for each observer (Figure 3.4). Before the observers assessed the set of video clips, they were informed about how we acquired the clips and about the two possible conditions (normal ventilation and pneumothorax). Due to the cropping and randomization, the observers were blinded for the diagnosis and for the transducer type.

The observers were requested to pause the playback themselves when they were certain about the diagnosis based on the presence or lack of lung sliding, A-line sign, or B-lines. The equal-

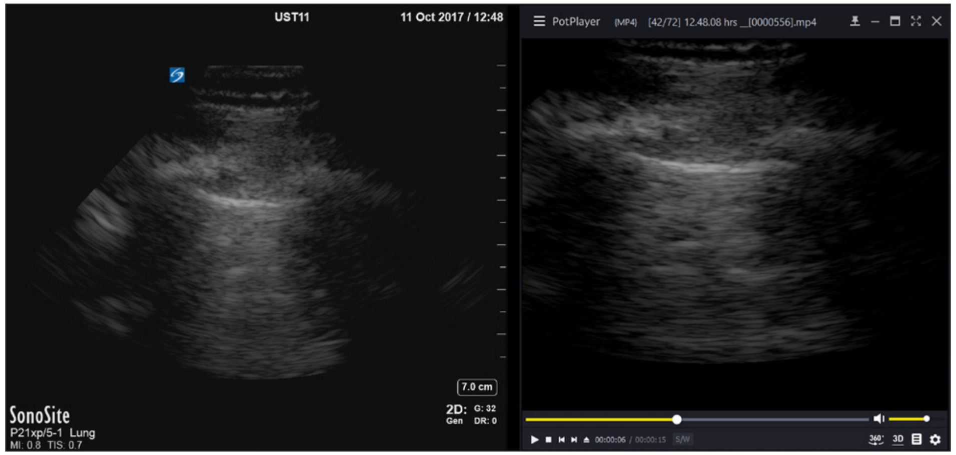

Figure 3.3 Typical uncropped and cropped image of the pleural interface

The image was acquired with a phased-array transducer. On the right, the cropped version is displayed as it was played back to the observers.

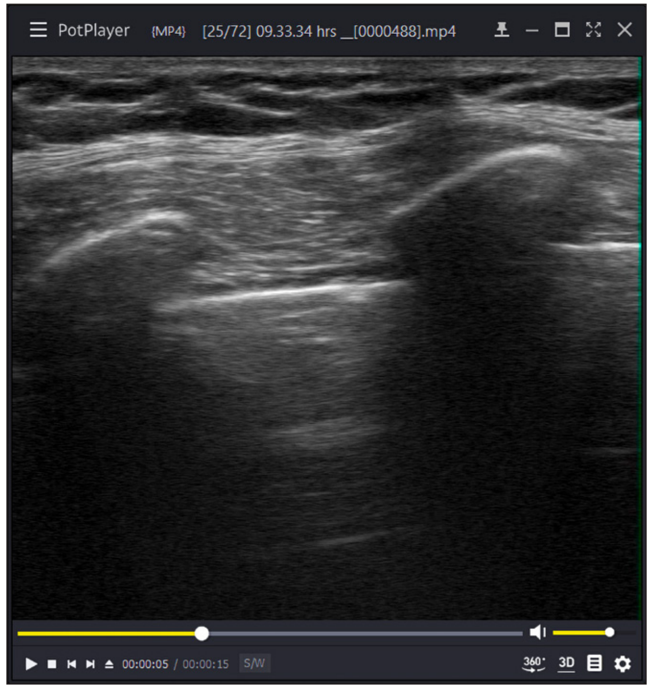

Figure 3.4 A cropped 15-second clip as it was played in random order to the observers

ly blinded researcher recorded the elapsed time (s), the observer's diagnosis and perceived image quality rated on a 1–5 Likert scale (1, very poor; 5, very good). For every observer, their experience (years) with lung US and preferred transducer type for lung US was recorded.

Statistical analysis

Normally distributed data are reported as mean and standard deviation (SD). Data with an asymmetrical distribution are reported as median and interquartile range (IQR). We calculated the difference in elapsed time and image quality between transducers in every patient and observer: linear-array vs curved-array; linear-array vs phased-array; curved-array vs phased-array. Then, we fitted a linear mixed model with a random intercept to these differences to account for clustering within each observer. A two-tailed McNemar's test for clustered data (Durkalski's Chi-square test) was used to test for differences between the transducers in diagnostic performance. The Wilcoxon signed-rank test was used to test for differences in time until final diagnosis between diagnoses (normal ventilation and pneumothorax). For all statistical tests, significance level was set to .05. For statistical analysis, IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA) and R, version 3.4.1, lme4 package installed (R Foundation for Statistical Computing, Vienna, Austria) were used.

Results

Patients

Sixty-six lung US video clips were acquired in 11 patients, of whom eight women, with a mean age of 64.0 years (± 9.03). Their mean weight was 66.1 kg (± 9.30), and the mean body mass index (BMI) was 24.3 kg m^{-2} (± 2.98). Surgery was performed on the left and right chest in four and seven cases, respectively. All participants had a pneumothorax after the surgeon opened the thorax.

3

Observers

The video clips were observed by 15 physicians of whom 13 HEMS physicians (nine anesthesiologists, and four trauma surgeons) and two anesthesiology residents. These observers all had extensive experience (a mean of 7.1 years [± 3.58]) in lung ultrasonography.

Prior to the observations, six observers indicated to prefer a linear-array transducer for lung ultrasonography. Seven preferred a phased-array transducer and two had no preference. The curved-array transducer was preferred by none.

Each observer assessed the 66 cropped clips in a random order. There was no significant difference between their different background for success rate (correct or incorrect diagnosis) or time they needed to assess the video clips.

In 10 of the 990 judged clips, an observer couldn't decide on the diagnosis because the image quality was perceived to be too bad. Therefore, for data analysis where the diagnosis is a factor we used the data on 980 clips. The time was recorded from the start of video playback to the moment the observer declared to be unable to state a diagnose.

Diagnostic performance

The overall sensitivity and specificity was 98.2% and 97.2%, positive predictive value (PPV) and negative predictive value (NPV) was 97.2% and 98.2%, respectively. A cross tabulation of the correct and incorrect diagnosis compared between transducers are displayed in Table 3.1.

The diagnostic performance measures for the different transducers for pneumothorax were calculated for 980 assessed clips and are displayed in Table 3.2.

McNemar's test for clustered data showed no significant difference in diagnostic performance between the different transducers. (Linear- vs curved-array: p = .706, linear- vs phased-array: p = .537, curved- vs phased-array: p = .515)

Table 3.1 Cross tabulation of the number of correct and incorrect diagnoses compared between transducers

	Diagnosis:	Correct	Incorrect	Total
		Curved-array transducer		
Linear-array transducer	Correct	313	7	**320**
	Incorrect	8	2	**10**
Total		**321**	**9**	**330**
		Phased-array transducer		
Linear-array transducer	Correct	308	12	**320**
	Incorrect	8	2	**10**
Total		**316**	**14**	**330**
		Phased-array transducer		
Curved-array transducer	Correct	309	12	**321**
	Incorrect	7	2	**9**
Total		**316**	**14**	**330**

Table 3.2 Diagnostic performance of the three ultrasound transducers for pneumothorax

	Linear-array transducer	Curved-array transducer	Phased-array transducer	All transducers combined
Sensitivity	97.5%	98.2%	98.8%	98.2%
Specificity	97.6%	96.4%	97.5%	97.2%

Time

The time the observers needed to reach a diagnosis is displayed in Table 3.3 and Figure 3.5.

After we fitted the linear mixed model, we found a significant difference between the time that elapsed until a final diagnosis was made. Whit the linear-array transducer the diagnosis was made 0.51 seconds (p = .031) faster compared with the phased-array transducer. The curved-array transducer was 0.15 seconds (p = .049) faster than the phased-array transducer. We found no significant difference between the linear- and curved-array transducers. These comparisons between transducers are displayed in Table 3.4.

3

Table 3.3 Elapsed time until a diagnosis was made

Diagnosis	Linear-array transducer	Curved-array transducer	Phased-array transducer	All transducers combined
Normal ventilation	2(1–5)	3(1–5.5)	3(2–5.5)	3(1–5)
Pneumothorax	5(3–7)	5(3–7)	6(3.5–8.5)	5(3–7)
All diagnoses[a]	4(2–6)	4(2–6)	4(2–7)	4(2–6.25)

a. This includes the ten clips without diagnosis.

The data are presented as median seconds (interquartile range).

Table 3.4 Difference in time elapsed until a diagnosis was made between transducer types

Compared transducers			Estimate [95% CI]	*p* value
Linear-array	vs	Curved-array	−0.35 [−0.78, 0.07]	.105
Linear-array	vs	Phased-array	−0.51 [−0.97, −0.05]	.031
Curved-array	vs	Phased-array	−0.15 [−0.59, 0.28]	.049

This table presents the differences in elapsed time until a diagnosis was made between a combination of two transducers, using a linear mixed model with a random intercept.

The differences are presented in seconds.

A negative value indicates that less time elapsed using the left of the two compared transducers.

Normal ventilation was diagnosed significantly faster than the diagnosis of a pneumothorax, regardless of transducer type. The Wilcoxon signed-rank test showed a significant difference overall ($p < .0001$) and within the three transducer groups as shown in Figure 3.5 ($p < .0001$ in all three groups).

Image quality

Image quality was scored on a 5-point Likert scale. The image quality of the linear-, curved-, and phased-array transducers was appreciated at a median of 4 (IQR 3–4), 3 (IQR 2–4); 2 (IQR 1–2), respectively. Overall image quality was rated a median of 3 (IQR 2–4). The distribution of the image quality scores per transducer type is displayed in Figure 3.6.

The Wilcoxon signed-rank test showed a significant difference in image quality between all three transducers ($p < .0001$).

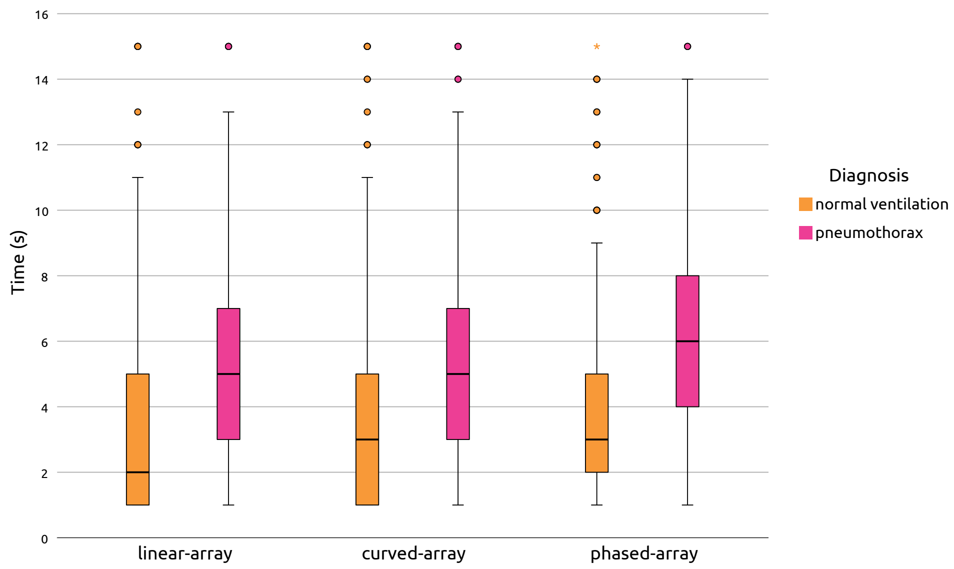

Figure 3.5 Boxplot of the elapsed time until a diagnosis was made compared between transducer types and diagnoses

The elapsed time until a diagnosis was stated by the observers. The time is represented in median seconds. The box represents the 25–75% interquartile range. The whiskers indicate the 95% confidence interval.

There is a significant difference in the elapsed time until a diagnosis was made between normal ventilation and pneumothorax within all three transducers ($p < .0001$).

After we fitted the linear mixed model, we found significant differences in image quality between all three transducers. The image quality with the linear-array transducer was 1.78 higher than the image quality with the phased-array transducer on a 5-point Likert scale. These comparisons in image quality between transducers are displayed in Table 3.5.

The image quality was deemed too bad to make a diagnosis in ten cases: 8 of 330 phased-array transducer clips and 2 of 330 linear-array transducer clips. Of those, seven clips showed a pneumothorax and three showed normal lung sliding.

3

Table 3.5 Difference in image quality between transducer types

Compared transducers			Estimate [95% CI]	*p* value
Linear-array	vs	Curved-array	0.53 [0.29, 0.76]	< .0001
Linear-array	vs	Phased-array	1.78 [1.56, 2.01]	< .0001
Curved-array	vs	Phased-array	1.25 [1.09, 1.42]	< .0001

This table presents the differences in reported image quality between a combination of two transducers, using a linear mixed model with a random intercept.
The image quality was reported on a 5-point Likert scale: 1, very poor; 5, very good.
A positive value indicates that the image quality was better with the left of the two compared transducers.

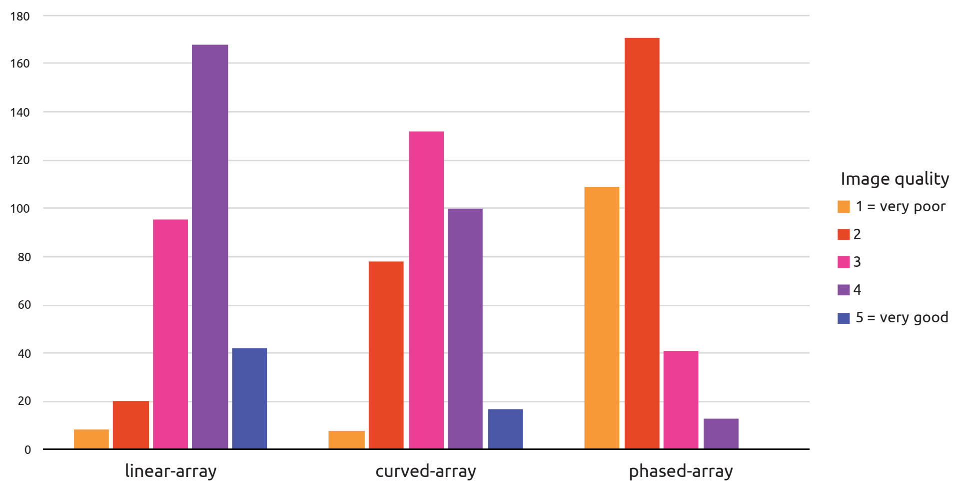

Figure 3.6 Clustered bar count of the image quality rating per transducer type

After we fitted the linear mixed model we found a significant difference in image quality between all three transducers ($p < .0001$) as displayed in Table 3.5.

Discussion

In this study we found no difference in the diagnostic performance of the linear-array, curved-array, and phased-array transducer. The diagnostic performance was very good: sensitivity, specificity, PPV, and NPV were all between 96.4% and 98.8%. The observers needed an additional 0.51 seconds to reach a final diagnosis with the phased-array transducer compared to the linear-array transducer. A final diagnosis was reached much faster when lung sliding was present regardless of the transducer type.

The image quality scored by the observers on a 1–5 scale was significantly different between all three transducers; the linear-array transducer achieved the best scores, the phased-array transducer the worst. Moreover, the image quality was too bad to reach a diagnosis in eight phased-array transducer clips and two linear-array transducer clips.

These findings suggest that the actual diagnostic performance of the three transducers for pneumothorax is comparable. However, these experienced observers perceived the best image quality and needed the least amount of time when they judged the linear-array transducer clips. Based on these findings the linear-array transducer might qualify as the preferred transducer for lung ultrasonography. However, the transducer choice may depend on more important factors such as the intended gamut of indications US is used for and whether the machine will be equipped with one or more transducers. In a single transducer setup, the best choice is probably a curved-array or a phased-array transducer to be able to evaluate both the abdomen and pericardium, in addition to the chest.

To our knowledge, there are no studies that have compared US transducers for diagnosing pneumothorax in a similar study design.

In a study with a comparable design, but not focused on pneumothorax, the authors compared a 10–5 MHz and a 14–5 MHz linear-array transducer for a wide array of emergency department point-of-care ultrasound indications.[15] However, lung ultrasonography was discussed only briefly. Overall, their observers most frequently preferred the 10–5 MHz transducer over the 14–5 MHz transducer.

In another study, the investigators compared a 5–10 MHz linear-array and a 1–5 MHz phased-array sector transducer in 55 patients scheduled for a thoracic computed tomography (CT) scan.[16] The authors evaluated the diagnostic performance for pneumothorax, pleural effusion, consolidation, and interstitial syndrome. In six patients with a pneumothorax, confirmed with CT, they found that the linear-array transducer performed best with a sensitivity and specificity of 83% and 100%, respectively. The phased-array transducer showed a sensitivity and specificity of 67% and 100%. Sensitivity of both auscultation and chest radiography was only 50%. In our study, the gold standard was a thoracoscopically induced and confirmed pneumothorax. Because we assessed 495 ultrasound clips showing pneumothorax, the diagnostic performance we found is more reliable.

We hypothesized that the linear-array transducer would have the best diagnostic performance. This study, however, showed no difference in diagnostic accuracy between the transducers.

The Nijmegen HEMS introduced prehospital ultrasonography to the Netherlands in 2006 and used a phased-array transducer ever since. Only years later, a linear-array transducer was added. A curved-array transducer has never been used. This history might explain the transducer preferences of the observers and the high and equal diagnostic performance between transducers.

Although diagnostic performance is equal, we recommend the linear-array transducer for (prehospital) lung ultrasonography. The diagnosis is made faster and with a better image quality. These are important advantages in the dynamic prehospital environment, HEMS physicians encounter challenges such as time pressure, limited working space, residual clothing, defibrillator pads, and Velcro® straps. Most importantly, the interpretation of US images may be hampered by sunlight or precipitation. When the HEMS physicians have the best possible image quality, they can better deal with these factors and do the best possible for our patients.

Furthermore, when the linear-array transducer is installed as the default transducer, it may have additional advantages. It is the preferred transducer for vascular access and assessment of the airway and endotracheal tube position.[15] These matters often take precedence over detailed assessment of breathing, although it may be of vital importance to be informed about a significant pneumothorax before airway management is commenced.

In addition, the linear-array transducer is superior for ultrasound-guided regional anesthesia (UGRA) in severely injured or trapped extremities and for optic nerve sheath diameter (ONSD) measurements in traumatic brain injury (TBI) patients.[17] For abdominal ultrasound and echocardiography, however, the phased-array or curved-array transducer is still invaluable.

The observers were able to successfully assess the video clips of normal ventilation and pneumothorax without having access to the US machine or the patient. This situation is comparable to a telemedicine setup in which the US operator could be at a different physical location than the observer of the images. Therefore, we agree that lung ultrasound can be successfully used in telemedicine setups.[18]

Strengths and limitations

We chose a unique approach to select VATS patients with a freshly induced and visually confirmed pneumothorax as the gold standard. Also, we included the video clips of the same patients with normal anatomy before surgery. Another unique aspect was the cropping of the video clips so transducers couldn't be identified by any text or image or sector shape.

A limitation of this study is that it might be underpowered because we couldn't demonstrate a difference in diagnostic performance between transducers. It could also mean the difference is close to none.

Another limitation is that we informed the observers that all patients were ventilated similarly and that besides a pneumothorax in half of the video clips, no other pathology was present. This could be an advantage for them judging the clips and might have resulted in an overestimation of the diagnostic performance and time needed. The performance could have been even better when we acquired M-mode clips looking for lung pulse or clips that included the lung point.[14]

Conversely, most observers were uncomfortable with the fact that they had to assess video clips and that they were therefore unable to reposition or adjust the transducer, adjust the gain or depth, or compare with the contralateral chest. Also, it was regarded a disadvantage that no additional clinical parameters were provided. The setting of pulmonary surgery introduced some minor challenges. In some clips, lung sliding was minimal, probably due to the lung-protective ventilator settings. B-lines were still present, obviously. In contrast to the normal clips, the pneumothorax clips were recorded with the transducer wrapped in a sterile cover. In theory, this might result in a slightly degraded US image.

Image quality might be overstated in video clips in which the diagnosis was made fast and perceived to be easy. Those clips might be scored good quality because they were 'easy' to assess.

A suggestion for future studies comparing ultrasound transducers might be to include subjects of all BMIs to better represent the general population of critically ill and injured patients.

Conclusion

In conclusion, we found no difference in the effectiveness of detecting or excluding a pneumothorax between a high-frequency linear-array ultrasound transducer, a curved-array, and a phased-array transducer. Besides many indications for which it is essential, the linear-array transducer produces the best image quality in lung ultrasonography. Based only on image quality, the linear-array transducer might qualify as the preferred transducer for lung ultrasonography and the preferred default in our prehospital setting.

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Part II

Ultrasonography in Dutch emergency departments

Chapter 4

Emergency physicians' attitudes to implementing ultrasound in Dutch emergency departments after a two-day training: a qualitative study

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Abstract

Background

Diagnostic ultrasound (US) is increasingly used by non-radiologists in trauma victims and critically ill patients. In the Emergency Department (ED), the extended focused assessment with sonography for trauma (eFAST), and polytrauma rapid echo-evaluation program (PREP) protocol are often used to assess these patients. Dutch PREP-trained Emergency Physicians (EPs) are implementing the use of US in the ED but might encounter barriers to overcome.

Objectives

This study aims to explore individual experiences of Dutch EPs.

Methods

We performed a qualitative study by conducting semi-structured interviews with Dutch EPs working in a Level 2 ED that have completed the two-day PREP course at least one year before the interviews. Data were analyzed using directed content analysis.

Results

Eight EPs employed by eight different hospitals were interviewed. Thirteen categories were identified in the transcribed interviews and these were combined into four general themes: (1) the desire to develop the Emergency Medicine specialty, both nationally and local; (2) incentives to start using US; (3) exploring practical applications of US; (4) barriers faced while implementing EP-performed US on the ED. The interviewees regard the course to be a solid base and are eager to independently perform US examinations although challenges are faced.

Conclusions

This exploratory study provides essential insight in Dutch EPs implementing US in their ED. It shows there is a need to develop a quality assurance system and it identified barriers that have to be dealt with.

Introduction

In trauma patients, diagnostic ultrasound (US) used by non-radiologists is becoming commonplace. It is used successfully in trauma victims and critically ill patients in the emergency department (ED), operating theatre, and in out-of-hospital settings. Also, it is used in remote locations such as the battlefield and outer space.[1,2]

US is used in the ED to answer simple yes/no questions that could make the difference detecting or ruling out life-threatening conditions such as pneumothorax, pericardial effusion, and intra-abdominal bleeding.[3–5] Therefore, life-saving interventions such as a tube thoracostomy may be performed more expeditiously, or prevented if deemed unnecessary.[6] Also, US may lead to a reduced usage of other imaging techniques such as chest X-rays and computed tomography (CT) scans.[7–10]

Various emergency US examination protocols are used. The extended focused assessment with sonography for trauma (eFAST) protocol assesses for free abdominal and pericardial fluid, and pneumothorax. In the Netherlands, the similar polytrauma rapid echo-evaluation program (PREP) protocol is widely used in EDs and in the prehospital setting.[11] Originally from Nîmes, France, it is taught and used in many European countries and Canada. It offers a uniform and fast five-step method to assess an injured or critically ill patient.[12]

During a two-day PREP course, the candidates are taught ultrasound theory and they will perform at least 20 supervised US examinations on fellow candidates, simulated patients in an ED or prehospital scenario, and peritoneal dialysis patients. The latter group of subjects carry a significant amount of fluid in the peritoneal cavity, resulting in a positive US scan mimicking intraperitoneal bleeding.

Non-radiologists can be effectively trained in a brief training to perform eFAST or PREP examinations.[13] Nonetheless, this skill needs to be maintained and improved by routinely using it in everyday practice. Its learning curve is estimated to level off at 30–100 US examinations.[14]

Although PREP-trained emergency physicians (EPs) are well prepared they are facing barriers. Emergency medicine is a young specialty in Dutch health care; in 1999 the Dutch association of emergency physicians (Nederlandse vereniging van spoedeisendehulpartsen, NVSHA) was formed and one year later the first three-year training programs started.[15] Implementation of US on the ED is frequently hampered by so called *turf battles*—about who should perform US on the ED—between radiologists and other medical specialists on the one hand, and EPs on the other.[16,17] Other complicating factors might be unavailable or unfamiliarity with US equipment, easily accessible conventional radiology and CT scanning, and EPs still lacking confidence in their recently acquired knowledge and skills.

Until now, there are no reports on how Dutch EPs implement their US knowledge and skills on the ED and what challenges they encounter. Therefore, the main objective of this study is to explore individual experiences of Dutch PREP-trained EPs who started routinely using US in their EDs.

Methods

Design

A qualitative study by means of semi-structured individual interviews was conducted in January and February 2014, to explore the subjects' perceptions and experiences. The Fontys University of Applied Sciences approved the study. Ethical approval was obtained from the institutional ethics review board of the Radboud university medical center, Nijmegen. Written informed consent was obtained from all participants.

Since this is a largely unexplored topic, the interviews were guided by an initial topic list aiming to identify the subjects' motivation (intention) and ability (behavioral control) to perform US examinations on the ED. Topics were based on three sources. First, topics were formulated to identify three factors (attitude towards the behavior, the subjective (social) norm, and perceived behavioral control) that influence the intention to perform a given behavior (performing US on the ED) as conceived in the theory of planned behavior by Fishbein and Ajzen.[18,19] This also includes any incentives and barriers influencing the behavior. Secondly, topics were based on earlier discussions the researchers had with other course candidates. Finally, one topic was based on previously mentioned turf battles.[16] The topic list is displayed in Table 4.1. Relevant new topics brought up by the interviewees were added to the list.

Recruitment and setting

We contacted randomly selected EPs who successfully completed the PREP course between one and four years preceding the study (2009–2012). After they agreed to participate they were further screened for possible inclusion.

Inclusion criteria were EPs employed at a Level 2 hospital for a minimum of 20 hours per week since completion of the course. In a Level 2 (ranging from 1–3, Level 1 being the highest) hospital seriously injured and critically ill patients can be treated although not all facilities, such as neurosurgery, are present. In these hospitals, EPs will have enough exposure to critically ill patients and opportunities to perform US examinations. Level 1 hospitals are generally well-equipped university hospitals where US examinations are typically performed by radiology residents. The interval between the course and interview was chosen to allow the EPs ample time to implement the use of US in their ED and to potentially experience any burden and challenges.

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Table 4.1 Motivated initial topic list

Interview topics	Example questions	Motivation
Experiences during the PREP course		Theory of planned behavior (attitude towards the behavior)
Presence and usage of a US machine	Does your ED own a US machine? If not, do you have access to an US machine?	Based on previous discussions with other course candidates
Indications for application of the PREP protocol	In which patients do you use the protocol? In which patients not?	Theory of planned behavior Based on previous discussions with other course candidates
Confidence in own US diagnosis		Theory of planned behavior (perceived behavioral control)
Relation of US with other diagnostics		Theory of planned behavior (subjective norm, perceived behavioral control)
US use by colleagues		Theory of planned behavior (subjective norm)
Cooperation with radiologists		*Turf battles* mentioned in literature

We excluded EPs who already performed PREP or eFAST US examinations, at least once a month, preceding the course.

Included subjects received written information in more detail in advance and written informed consent was given prior to the interview. Further inclusion of subjects was continued until no more new codes were determined during the interview process and data saturation was reached.

Procedure

Subjects were interviewed at their own workplace by a trained interviewer (EvH). The interviews were conducted face-to-face in a secluded room without disturbances. Open-ended questions based on the initial topic list were used to initiate the conversations. The interviews were conducted in Dutch and audio-recorded. The mean duration of the interviews was 26 minutes. Notes on non-verbal communication were taken. Member checks were performed: every participant was invited to read and comment on a summary of the transcription.

Table 4.2 Categories and themes related to the initial topic list and newly identified categories

Theme	Category	Initial topic list or added
Development of EM specialty	Recognition of Emergency Medicine as an official specialty	Added
	Importance of US on the Emergency Department	Added
	Quality assurance of US skills	Added
Incentives to start using US	Experiences during the PREP course and motivation for signing up	Initial
	US use by colleagues	Initial
Practical application of US	Indication for application of the PREP protocol	Initial
	Application of US beyond the scope of the PREP protocol	Added
	Relation of US with other diagnostics	Initial
Barriers	Presence and usage of a US machine	Initial
	Cooperation with radiologists	Initial
	Confidence in own US diagnosis	Initial
	Additional barriers	Added

US, ultrasound; PREP, polytrauma rapid echo-evaluation program; EM, emergency medicine; EP, emergency physician.

Data analysis

Every interview was transcribed verbatim and analyzed directly afterwards. The transcriptions were subjected to thematic content analysis, inspired by the work of Braun and Clarke.[20] Thematic analysis was performed using a constant comparative (iterative) method using the OpenCode application (OpenCode 4.0.2. University of Umeå, Sweden). After every transcribed interview, relevant data extracts were selected and coded. New codes were added to the code tree and used in coding of the next transcript. After coding all transcripts, codes were combined into categories using axial coding to match those in the initial topic list, if appropriate. Newly identified categories were added to the list. The data were selectively coded to bring previously defined categories together into themes to see the bigger picture.

Transcripts were anonymized before coding. After completion of the study, data that could trace to an individual subject, including audio recordings, were discarded.

Results

Participants' characteristics

A total of eight EPs (3 males, 5 females) were interviewed, employed by eight different Level 2 hospitals.

Data analysis and themes

Coding resulted in 225 open codes. These were combined into 13 categories. Next, we identified four themes as displayed in Table 4.2. Some codes were associated with multiple categories and themes.

Themes

- Development of the Emergency Medicine specialty
    - » Importance of US on the ED and the recognition of EPs as a medical specialty

EPs are relative newcomers in Dutch healthcare. Ever since their introduction, skills and responsibilities have begun shifting.

Participants have stressed the importance to improve the recognition of their medical specialty and wanted to show their added value to the hospital. According to some, implementing US clearly contributes to these goals. They experienced criticism from other specialties:

> "However, in the Netherlands there are some scientific associations, such as anesthesiology and internal medicine, that still express some criticism regarding the presence of EPs. And yes, I believe this has to do with a feeling of land grabbing." (p.2)

> "And then it is difficult to bring into the limelight that we also largely fill in a new area. And are taking over a non-existent area." (p.3)

In addition to recognition of the specialty, implementation of US on the ED would yield independence, time saving, and logistical advantages.

> "And I think it is super convenient no longer having to depend on radiologists that I have to call into the hospital or to have patient undergo US examinations in places that are not safe for them

to be at." (p.3)

"So yes, for that matter, I can see the added value. It is an imaging technique that is fast to perform. Basically, it takes a few minutes to complete an US examination." (p.2)

"When I do an US examination and detect free fluid, I'm not afraid to be energetic and rush the patient to the CT scanner. That is added value, the logistics process." (p.3)

» Quality assurance of skills

In over half of the hospitals, EPs were looking for a suitable quality assurance system. In one hospital, together with radiologists they developed an in-hospital training program. In another, they planned to commence radiologist-supervised US examinations.

Quality assurance of US skills was frequently mentioned. On the one hand, individual responsibility was highlighted.

"Yes, I believe that during time one has to develop their skills. You then have to decide for yourself whether to make official statements about your examinations or not." (p.7)

On the other hand, there appeared to be a clear need for a certification system in which knowledge and skills would be documented. On one ED, the EPs themselves determined that they were not qualified to perform diagnostic US scans.

"Well, the biggest objection the other consultants had to implementing US on the ED was they couldn't tell how our knowledge and skills were going to be assured. We discussed this and realized we couldn't tell either. So, they are right! We feel it is important and we want to practice so we can take US usage by EPs to another level. But now we are not ready for it, yet." (p.6)

Others reported initial suspicion as well but took a different approach.

"I can really empathize with the surgeon who witnesses an EP do an US examination he has never seen do one before and then wonders: are you sure you can do this? I feel that is a logical reaction. And it is up to us to prove this can be implemented for years to come. It will take time, but that's the case for a lot of novelties." (p.2)

Five out of eight participants were developing a system to document every EP's US skills. Frequently mentioned was the performance of radiologist-supervised examinations.

"We have agreed with the radiologists we will actually, for a certain period of time, will do it really together. So, they will stand next to us and supervise. And from the moment they will say they are confident enough, they will supervise us from a distance." (p.8)

"But ideally our knowledge and skills will be tested by a very wise person, the radiologist, and says: 'Indeed, you can do that well enough'." (p.3)

Incentives to start using US

» Motivation to sign up and experiences during the PREP course

Course participants regarded the PREP course to be very instructive and primarily a basic course to start learning US.

"You are scanning the same set of regions and the US approach to those regions is always the same. I think that is very good of PREP. It doesn't teach everything I could possibly make an image of. It only teaches to produce a standard image on the screen. It is all for dummies." (p.3)

Peritoneal dialysis patients are recruited to serve as models during the course. Two participants explicitly appointed this to be of added value to the course.

Another basic US course covering a range of topics including e-FAST is organized by the Dutch Association of emergency physicians NVSHA. Two participants indicated to prefer this over the PREP course.

"At this moment, I would pick the NVSHA course, rather than the PREP. But it wasn't available at that time." (p.6)

» Ultrasound use by colleagues

A motivation to start using US in general was that some colleagues were using US already. We asked the EPs thy they signed up for the PREP course.

"Why? Because one of my colleagues who participated earlier told me about it. She was very excited about the course!" (p.2)

Conversely, another was struggling stimulating colleagues to use US.

"I have to put in a lot of effort to get my colleagues on board. Some colleagues get cold feet. I sup-

> pose they find it difficult to draw conclusions from their ultrasound images. That is the hardest part of it, I suppose, because just putting a transducer on somebody is easy!" (p.5)

Multiple participants said every EP should be proficient in emergency US.

> "I wanted to sign up for the course because I feel that being an EP means you must be able to do an emergency US examination. And that's very important." (p.7)

> "I brought up the subject again at our latest meeting. I believe the other consultants should be able to count on us to all have equal high standards and skills." (p.5)

Practical application for US

Indication for application of the PREP protocol

Some participants felt that US is not always indicated in a patient that sustained high-energy trauma and that it's more important to let the clinical picture prevail:

> "ATLS dictates: assess the patient and based on the clinical picture a US examination is done." (p.2)

Conversely, participants told that US examinations are performed on patients with minor injury without much pain. It is then regarded as an opportunity to practice US skills, without an obvious indication. In fact, this opportunity was regarded as a separate indication. Other reported indications were abdominal pain, cardiovascular instability, distracting injury, intoxication, and undifferentiated shock.

One participant only performed US examinations in patients with a low probability of serious injury. In every other case, the radiologist was consulted.

> "The bottom line is that on the patients with low suspicion (...) from whom you expect no real injury (...) those cases we use the US on." (p.1)

Application of US beyond the scope of the PREP protocol

Several participants describe the PREP course as a stepping stone to start with US in the ED. They were excited about the different US applications they discovered after having completed the course. Deep venous thrombosis (DVT), hypotension, intravenous access, regional anesthesia, hydronephrosis, kidney and gallstones, foreign bodies, Achilles tendon rupture, fracture position (after repositioning), and inferior vena cava (IVC) measurements for volume status were mentioned.

"We are continuously expanding, also in respect to US. We will be using US for DVT as well. Um, so yes, we are expanding, but specifically within the scope of emergency US." (p.7)

Relation of US with other diagnostics

All participants agreed that US examination has taken a prominent place in diagnostic imaging techniques and was considered by some participants for certain indications to be more reliable than chest X-ray.

> "For instance, in a trauma victim with suspected pneumothorax, we will put more confidence in our own US than in one supine chest X-ray without pathology." (p.4)

US might replace some other imaging techniques, too.

> "In the case of a hemodynamically instable patient, we actually let it guide treatment decisions. If the patient is suspected of intra-abdominal injury and there is also free fluid detected by US... Well, we put two and two together and rush the patient to surgery." (p.8)

Whenever US was followed by another imaging technique, this was considered to be an important verification.

> "Whenever, for instance, a CT scan is performed, to us there is the added value to verify the results of our US examination. That is very important to us." (p.7)

Conversely, gaining experience by performing an US examination after a diagnosis is made with other diagnostics was also mentioned.

> "... the other day there was a pneumothorax. I thought: ah, let's have a look with ultrasound. You know, let's see if I can see it, too." (p.1)

Barriers

Presence and usage of a US machine

In four out of eight hospitals, the ED owned an US machine. Three departments have entered into a loan agreement with either the radiology or urology department. One ED had no disposal of a US machine at all.

"We are working on it. Together with the radiologists." (p.8)

On another ED where no US machine was available when requested the (resident) radiologist would visit and bring the US machine. They then allowed the EP to perform the actual US examination.

» Cooperation with radiologists

We noticed significant differences in the way the EPs cooperated with the radiology department. In one hospital EPs were not allowed to perform US examinations by themselves.

"That is what we agreed on with the radiologists. Whenever an US examination is warranted, we do one first and the radiologist repeats it afterwards." (p.6)

In multiple hospitals, the radiologists preferred the EPs to perform the US examinations themselves.

"At our hospital radiologists are very satisfied with us doing the US scans on trauma victims. During night and weekend shifts for instance, they then don't have to rush into the hospital." (p.7)

"We have a very good relationship with the radiology department. They really do understand, but some are genuinely concerned about possible degradation of the quality of US exams. And I believe that is a legitimate concern." (p.3)

"Besides that, there is an issue that radiology residents have to make sure they perform enough US exams of their own so they develop their skills, too." (p.6)

In some other hospitals, the sentiment regarding EPs using US was quite different.

"Some radiologists aren't very happy with us doing US exams. And neither are some of the other consultants. Some consultants are very comfortable with us performing the exams, and others just aren't." (p.6)

This phenomenon has been called land grabbing and gives rise to political debate.

"... it is just land grabbing. Is has got nothing to do with them thinking we can't do US examinations. They will claim that's the reason. But hey, US scanning is just like an intubation. Anyone can be taught how to do it." (p.2)

"I do remember that when we got our first US machine and especially afterwards, at the political level there has been quite some quibbling about it. The radiologists still feel US belongs to them. Obviously, it is no longer true that certain diagnostic techniques are a prerogative of a particular discipline." (p.2)

» Confidence in own US diagnosis

There was a wide variety in the degree of confidence that each participant had in their US diagnosis.

"I lack the confidence, so I always ask somebody else to do another US examination." (p.6)

"in 95% of cases I'm confident about my diagnosis." (p.4)

"I do the exam myself, I interpret it myself, and if necessary I take action." (p.5)

The importance of practice was emphasized and it was mentioned that after 50 examinations confidence would grow.

"You just have to do it often and must expose yourself to repeated US examinations and that just requires an investment of time and energy. A lot of time has to be invested." (p.1)

Differences in perceived difficulty between assessment of the chest and abdomen appear to be personal.

"Well, it can be hard sometimes to detect a pneumothorax. Free intraperitoneal fluid, on the other hand, isn't hard to detect at all." (p.2)

» Additional barriers

In addition to the lack of a US machine preventing the use of US, other limitations were a lack of time and a shared responsibility between physicians for a patient.

"Whenever there is an indication to do an US examination and, um, I am there, I'll do it myself primarily. If there is a lack of time or somebody else is caring for the patient, then I'll call the radiologists." (p.2)

Discussion

In this study, we mapped the factors influencing the experience, confidence and practical application of emergency US. Every EP valued the use of US and it was described to be an indispensable tool in daily practice. They were highly motivated to use their new skills. This is in concordance with the results of Heinzow et al. who interviewed a group of medical students before and immediately after a basic ultrasound course and also found them to be highly motivated to apply the newly acquired US skills in daily practice.[21]

In the Netherlands, no guidelines exist on the implementation of EP-performed emergency US on the ED. Every ED has the responsibility to assign specific (US) qualifications to the individual physicians. EDs in the United States, however, adhere to the Ultrasound Guidelines, developed by the American College of Emergency Physicians (ACEP).[22] These guidelines are helpful starting an emergency US program and provide recommendations for proper implementation of emergency ultrasound on the ED, including a minimum number of clinical training hours.

The cooperation with the radiology department appeared to be very agreeable in some hospitals, while in others, tensions were reported. Participants indicated that radiologists themselves, rightly or wrongly, were concerned about the quality of EP-performed US examinations. Therefore, we would recommend the development of national guidelines comparable to the ACEP.

This study shows that there is a need for a quality assurance system for US skills. The purpose of such a system may be to keep a record of every EPs knowledge and skills. It might consist of course certificates and a collection of stored US images or video clips demonstrably supervised by radiologists or expert colleagues. In one hospital, a lack of quality assurance resulted in mandatory verification of every US examination by a radiologist. In another, EPs are simply relying on the skills of their colleagues. Meanwhile, a Dutch US certification program for EPs has been adopted by the general assembly of the NVSHA in June 2017.

US training has recently become a compulsory item in the residents' curriculum. It is essential to remain confident with the PREP protocol and US images. Therefore, it is advised to schedule regular practice to improve on speed, accuracy, and recognition of negative US images in healthy subjects. Regular practice should be part of the quality assurance system.

Budhram reported an effective emergency US training program for EPs, including eFAST. The participant's goal was to complete and record 25 technically adequate eFAST studies on their EDs. To record the knowledge and skills on every participant's ED, and for quality assurance, an on-site archiving system was put in place.[23] They also observed the turf battles: the radiology department questioned the EP's competency and they feared a reduction in their department's study volumes.

Strength and Limitations

This study yields new information about the experiences of Dutch EPs running a US protocol in practice. We gained insight in the role of Dutch EPs on their EDs, their collaboration with colleagues, the varying levels of confidence, and the need for a quality assurance system. Because we used open-ended questions, new topics emerged that complemented the initial topic list.

A limitation of the study is that one researcher coded the transcripts. This might impact the reliability of coding. Furthermore, this study is limited in its scope by including a homogenous group of EPs employed by Level 2 hospitals only. Also including EPs from Level 1 and 3 hospitals, might have produced a more complete overview.

To successfully implement US, EPs should focus on the development of a quality assurance system. However, it remains unclear whether a uniform (national) system is preferred or departments prefer to develop their own system.

Furthermore, emergency ultrasound should be defined more clearly to benefit accreditation and uniformity. The ACEP Ultrasound Guidelines include a list of basic US applications considered part of emergency ultrasound.[22]

Conclusions

This exploratory study provides essential insight in Dutch EPs implementing US on their ED which could be further studied in a national survey with all EPs. Furthermore, the study shows that there is a need to develop a quality assurance system and barriers to overcome were identified. Every EP recognized the importance of EP-performed emergency US and regarded it an indispensable tool in daily practice and of value for the recognition of their specialty. The EPs all valued the PREP protocol to be a solid foundation when starting to learn and implement emergency US. All stressed the importance of practice.

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Epilogue

This study was conducted in the winter of 2014. This thesis was completed four years later. In the meantime, the Dutch EPs have made some substantial progress in the adoption and implementation of emergency department ultrasonography.

Much more emergency departments have now gained access to an ultrasound machine. Furthermore, basic ultrasonography training has become an integral part of the first year of the emergency medicine residents' training curriculum.

In June 2017, the Dutch association of emergency physicians (NVSHA) adopted a program for EPs to become certified in basic emergency ultrasonography. EPs choosing to become an NVSHA-certified basic emergency ultrasonography provider must (1) participate in a two-day course, and (2) perform and record 250 examinations: 25 supervised and 25 unsupervised examinations in five distinct areas. These areas include (1) eFAST, (2) focused cardiac ultrasonography, and ultrasonography of the (3) abdominal aorta, (4) inferior vena cava, and (5) lung. The certification is concluded with a written test and a practical exam.

The certification program is available to EPs that have completed their training and it will be implemented in the emergency medicine residents' training curriculum in the near future.

Hence, many of the obstacles that this study identified are being resolved to varying degrees.

First, the obstacle of unavailable US machines is resolving gradually through the merits of individual EPs and EDs that acquire their own devices. The popularity of emergency ultrasonography and the improving availability of devices might be helpful in this process.

Secondly, the lack of certification will now be resolved by the NVSHA in the coming years. Every EP and emergency medicine resident is now encouraged to become NVSHA-certified in basic emergency ultrasonography.

Thirdly, implementing basic emergency ultrasonography in the training curriculum and promoting the certification program will hopefully improve the EPs' confidence in their skills and ultrasound diagnoses.

Finally, the three aforementioned improvements and the continued penetration of emergency ultrasonography in the Dutch EDs will ultimately arouse the interest of the radiologists and strengthen collaboration with the EPs.

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4

Chapter 5

Emergency physician-performed ultrasound-guided nerve blocks in proximal femoral fractures provide safe and effective pain relief: a prospective observational study in the Netherlands

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Abstract

Background

The treatment of acute pain in the emergency department is not always optimal. Peripheral nerve blocks using "blind" or nerve stimulator techniques have substantial disadvantages. Ultrasound-guided regional anesthesia may provide quick, safe, and effective pain relief in patients with proximal femoral fractures with severe pain. However, no evidence exists on emergency physician-performed ultrasound-guided regional anesthesia in these patients in Dutch emergency departments. We hypothesized that emergency physicians can be effectively trained to safely perform and implement ultrasound-guided femoral nerve blocks, resulting in effective pain relief in patients with proximal femoral fractures.

Methods

In this prospective observational study, emergency physicians were trained by expert anesthesiologists to perform ultrasound-guided femoral nerve blocks during a single-day course. Femoral nerve blocks were performed on patients with proximal femoral fractures. A system of direct supervision by skilled anesthesiologists and residents was put in place.

Results

A total of 64 femoral nerve blocks were performed. After 30 min, blocks were effective in 69% of patients, and after 60 min, in 83.3%. The mean reduction in pain scores after 30 and 60 min was 3.84 and 4.77, respectively (both $p < 0.001$). Patients reported a mean satisfaction of 8.42 (1–10 scale). No adverse events occurred.

Conclusions

Ultrasound-guided femoral nerve block is an effective, safe, and easy to learn (single-day course) procedure for emergency physicians to implement and perform in the emergency department. Patient satisfaction was high.

Introduction

The treatment of acute pain in emergency department (ED) patients is not always optimal.[1,2] Fortunately, in patients with proximal femoral fractures, peripheral nerve blocks are used increasingly to obtain adequate pain relief.[3–6] In addition to providing pain relief, it may decrease the administration of systemic analgesics such as opioids and decrease their side-effects.[7,8] Also, undertreated pain and inadequate analgesia have the potential to cause delirium in patients with proximal femoral fractures.[9] Fascia iliaca compartment blocks (FICB) have been performed in hip surgery patients and have shown the potential to reduce the incidence of perioperative delirium in these patients.[10]

Nerve blocks in femoral neck fracture patients can be achieved using different techniques. The FICB is a "blind" technique in which surface anatomy landmarks are used to determine the needle insertion point, and tactile feedback guides the correct needle position. Techniques based on surface landmarks have a higher incidence of paresthesia during performance of the block.[11] Furthermore, they produce blocks with a slower onset, lower quality, and shorter duration compared to an ultrasound-guided technique.[4,11,12] A nerve stimulator-guided femoral nerve block makes use of electrical nerve stimulation to locate the femoral nerve. If a minimal electrical current still elicits quadriceps muscle contractions, the optimal needle tip position is obtained. Especially in proximal femoral fracture patients, these contractions may be painful and are therefore undesirable.[4]

Ultrasound-guided nerve blocks may overcome the aforementioned drawbacks. Ultrasonography allows identification of relevant anatomical structures and continuous needle tip visualization, and even the spread of local anesthetic (LA) may be observed. Ultrasonography in regional anesthesia has increased the success rate and reduced the complications of peripheral nerve blocks.[13]

Traditionally, only anesthesiologists performed ultrasound-guided regional anesthesia (UGRA). In recent years, though, emergency physicians (EPs) have been adopting this technique.[14–16] However, in the Netherlands, a lack of evidence exists on EP-performed UGRA in proximal femoral fracture patients.

An ultrasound-guided femoral nerve block and FICB appears to provide quick, safe, and effective acute pain relief and could therefore be a valuable tool adding to current pain management regimes in Dutch EDs.[7,17] However, EPs should gain relevant knowledge on basic ultrasonography, local anesthetics, nerve block indications, relevant anatomy, block techniques, and complications. Relevant skills to acquire are ultrasound scanning techniques, recognizing sonoanatomy, and ultrasound-guided needle handling. We hypothesize that EPs can be effectively trained to safely perform ultrasound-guided femoral nerve blocks, resulting in effective pain relief in patients with proximal femoral fractures.

Methods

Design

A prospective observational study in ED patients with proximal femoral fractures was conducted from June 2014 until June 2017. The aim of the study was to evaluate the effectiveness, safety, and satisfaction of EP-performed ultrasound-guided nerve blocks in the emergency department. The study was deemed exempt from formal review by the regional ethics review board of Arnhem and Nijmegen, and approval was obtained from the institutional review board of the Radboud university medical center. Before the nerve blocks was performed, oral informed consent was asked and obtained as part of the standard operating procedure.

Recruitment and setting

Adult patients admitted to the Radboud university medical center ED with a proximal femoral fracture, including trochanteric and femoral neck fractures, in whom an ultrasound-guided femoral nerve block or FICB was planned in the ED were included. Exclusion criteria were any sign of infection at the injection site, hemorrhagic diathesis (e.g., hemophilia and use of anticoagulant drugs with international normalized ratio (INR) > 2.0), an allergy to ropivacaine, and multiple traumata.

A 1-day course and an e-learning module were developed by a collaboration of anesthesiologists with extensive experience in UGRA and EPs experienced in general ultrasound. Every EP and EP in training participated in this hands-on course focusing on UGRA of the femoral nerve and FICB. The online pre-course e-learning module and course lectures dealt with basic theory of ultrasound, pharmacology of local anesthetics, indications, relevant anatomy, block techniques, complications and their treatment, and follow-up. Live anatomy and practical block techniques were taught on human cadavers at the Radboud Anatomy Department. Scanning techniques and sonoanatomy were taught and practiced on the participants themselves. Ultrasound-guided needle handling was practiced on blocks of tofu with tiny artifacts inserted.

The UGRA-trained EPs were supervised by skilled (resident) anesthesiologists for five, or more if desired, ultrasound-guided femoral nerve blocks or FICBs until the EPs had gained the knowledge, expertise (as judged by the anesthesiologist), and confidence to perform the procedure independently. A dedicated pool of anesthesiologists and residents with extensive experience in UGRA provided immediate and direct supervision on weekdays during regular business hours. Outside of these hours, supervision was provided depending on the availability of a skilled anesthesiologist or resident.

Before the ultrasound-guided femoral nerve block or FICB was performed, oral informed consent was obtained as part of the standard operating procedure (SOP). No sedative premedication was administered prior to the procedure.

The ED SOP was jointly written by anesthesiologists and EPs, in accordance with the existing SOP for ultrasound-guided femoral nerve blocks performed by anesthesiologists in the operating room. It prescribes a sterile procedure and a conservative maximal LA dosage to minimize risks of local anesthetic systemic toxicity (LAST). Vital parameters (continuous electrocardiogram, pulse rate, oxygen saturation, respiratory rate, and blood pressure) are monitored and continued for 30 min after the procedure. The skin is prepped and draped, and face masks, caps, sterile gloves, and a sterile probe cover are donned. Sterile ultrasound transmission gel and a Stimuplex® Ultra 22G 0.64 × 50 mm, 30°, short bevel (B. Braun, Melsungen, Germany) non-traumatic needle are used. The LA consists of ropivacaine 0.375%, in (four) labeled 10 ml syringes, to allow for a high-volume block without exceeding the maximum dosage. Alternatively, ropivacaine 0.75%, which is also used by anesthesiologists for providing surgical pain relief, can be used. The maximum allowed dose of LA is 2 mg kg^{-1} body weight of ropivacaine, injected in 1–2 ml increments under direct ultrasound guidance to confirm the optimal spread of LA around the femoral nerve or below the iliac fascia (FICB). Negative aspiration is confirmed at least every 5 ml to prevent intravascular injection.

In addition to the EPs and EPs in training, all ED nurses were trained to be familiar with the SOP and to be able to assist in the procedures.

The procedure was recorded in the electronic medical record (EMR) according to the SOP. Relevant and additional data were recorded on a dedicated case report form, including gender, age, fracture type and location, and prehospitally administered analgesics (type, dosage, and route of administration). The indication and type of the nerve block, LA dosage, scores on physician and patient satisfaction, pain scores, any rescue medication, adverse events, and any reason to abandon the procedure were also recorded. Vital signs were recorded only in the EMR.

Pain scores were taken in rest on a numeric rating scale (NRS; 0–10) on arrival at the ED (t0) and after the procedure at 30, 60, and 120 min (t30, t60, and t120, respectively), but only if still in the ED. We considered a nerve block to be successful whenever there was a pain reduction of at least two points after 30 min compared to baseline. We considered a pain reduction of at least 33% to be clinically important, as inspired by the work of Farrar.[18] An absolute pain score of 4 or less, though, was considered acceptable pain.

Just before discharge from the ED, patients were asked about the level of (dis)comfort they experienced and if they were motivated to undergo a similar procedure in the future. In addition, EPs self-reported five attributes of the procedure. These attributes were scored on a 1–10 rating scale as shown in Table 5.1.

Statistical analysis

Normally distributed data are reported as mean ± standard deviation (*SD*) or 95% confidence interval (CI), and data with a skewed distribution, including absolute pain scores, are reported as median with an interquartile range (IQR). A one-tailed paired Wilcoxon test was used to test for differences in pain scores within subjects because these are ordinal values, not normally distributed. To test for differences between subgroups in relative and absolute pain score changes (normally distributed), a *t*-test and a one-way ANOVA was used. Pearson correlation was calculated for the influence of age and injected volume of LA. Statistical significance was considered at $p < .05$. For statistical analysis, IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA), and GraphPad Prism version 5.00 for Windows (GraphPad Software, San Diego, CA, USA) were used.

Table 5.1 Attributes of the ultrasound-guided regional anesthesia procedure

Attribute	Score – 1	Score – 10
Patient		
(Dis)comfort experienced during the procedure	very uncomfortable	not uncomfortable at all
Would like to undergo a similar procedure in the future	would like it never again	would like it again
Emergency Physician		
Ease of the procedure	very difficult	very easy
Success of procedure itself regardless of the effect	did not succeed at all	very successful procedure
Visibility of anatomical structures on ultrasound	hard to recognize	easy to recognize
Spread of local anesthetic on ultrasound	bad spread	good spread
Subjective added value of procedure to patient care	no added value	absolute added value

These attributes were to be reported by the patients and self-reported by emergency physicians on a 1-10 numeric rating scale.

Results

In total, 64 patients (23 males, 41 females) received UGRA by EPs in the ED for a proximal femoral fracture. Demographics, types of fractures, and prehospitally administered analgesics are displayed in Table 5.2.

Fourteen EPs and EPs in training performed on average 4.6 (95% CI: 3.1, 6.0) ultrasound-guided nerve blocks of which 13 (20.3%) were FICBs and 51 (79.7%) femoral nerve blocks.

Ropivacaine 0.375% was used in 28 (43.8%) patients with a mean volume of 22.8 ml (± 6.6 ml, range 13–40 ml). Ropivacaine 0.75% was used in 36 (56.3%) patients with a mean volume of 18.9 ml (± 2.9 ml, range 10–20 ml). All blocks proceeded uneventfully, although one patient with mild pain on injection and one event of transient periprocedural hypotension, unrelated to LA injection, were reported.

Table 5.2 Demographics and type of fracture

Factors	Frequency or value	%	Range
Median age (IQR), years	76 (68–84)		28–95
Gender			
Male	23	35.9	
Female	41	64.1	
Type of fracture			
Femoral neck	37	57.8	
Trochanteric	16	25.0	
Femoral shaft	11	17.2	
Laterality			
Left femur	30	46.9	
Right femur	34	53.1	
Prehospital analgesics			
Rate of administration	51	79.7	
Paracetamol/Acetaminophen	19	37.3	
NSAIDs	–	–	
Oxycodone	1	2.0	
Fentanyl	26	51.0	
Morphine	6	11.8	
Esketamine	14	27.5	

IQR, interquartile range; NSAIDs, nonsteroidal anti-inflammatory drugs.

Patient perspective

The median pain score on an NRS at baseline (t0) before UGRA was 8 (IQR 5–9). At 30 min (t30) after the nerve block, the median score was significantly reduced to 3 (IQR 2–5, $p < .001$). The pain was significantly reduced even further to 2 (IQR 0–4) at t60 and to 1 (IQR 0–1) at t120. Relative and absolute pain reductions are shown in Table 5.3 and Figure 5.1.

Patient-reported (dis)comfort was scored a median of 8 (IQR 8–9, n = 61). When asked if they were motivated to undergo a similar procedure in the future, the score was 9 (IQR 8–10, n = 60).

Pain reduction was not found to be significantly related to gender, age, fracture types, prehospital administration (and type) of analgesics, the two block types, the two different concentrations of ropivacaine, or volume of injected LA. Also, we found no significant difference in pain reduction at t30, t60, and t120, whether the EPs performed the blocks with or without supervision. As shown in Table 5.4.

EP perspective

The 1-day course was very well received, and the EPs were enthusiastic about starting to perform the nerve blocks after the course. The median scores, IQR in parentheses, of the self-reported qualifications of the procedure (n = 59) were ease of procedure 8 (7–9), success of procedure itself, regardless of the effect 9 (8–10), visibility of anatomical structures on ultrasound 8 (7–9), spread of local anesthetic 9 (8–10), and subjective added value of the procedure to patient care 9 (8–10).

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Table 5.3 Pain scores and reduction from baseline at 30, 60, and 120 minutes

	n (%)	NRS, median (IQR)	NRS ≤ 4 *n* (%)	Pain reduction ≥ 33% *n* (%)	Pain reduction	95% CI	*p* value
Baseline	64 (100)	8 (5–9)	6 (9.4%)	-	-		
t30	58 (90.6)	3 (2–5)	40 (69.0)	41 (70.7)	3.84	3.15, 4.54	< .001
					50.9 %	42.6, 59.2	< .001
t60	30 (46.9)	2 (0–4)	25 (83.3)	24 (80.0)	4.77	3.73, 5.80	< .001
					64.4 %	52.1, 76.8	< .001
t120	7 (10.9)	1 (0–1)	6 (85.7)	6 (85.7)	5.85	2.72, 8.99	.002
					79.5 %	46.3, 100.0	< .001

Median pain scores at baseline, 30, 60, and 120 minutes.
Pain scores of four and lower, pain reduction within subjects of at least 33%, overall pain reduction relative and in numeric rating scale (NRS) points including 95% confidence interval (CI) and *p* value.

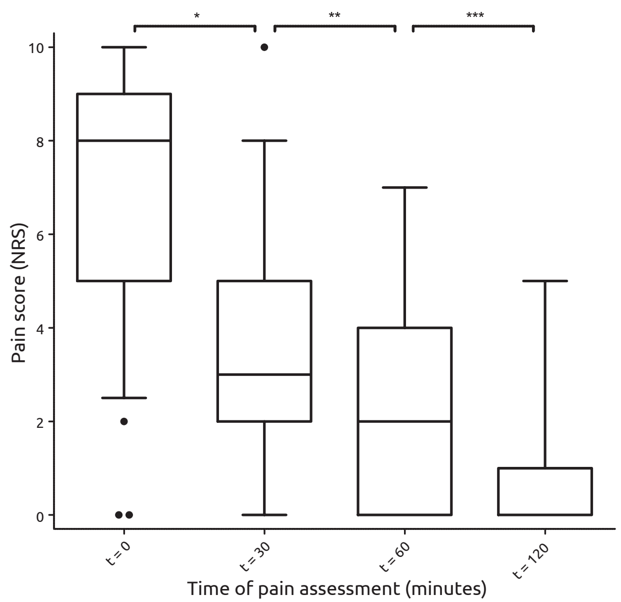

Figure 5.1 Pain scores at baseline and at 30, 60, and 120 minutes

Pain scores measured after an emergency physician-performed ultrasound-guided nerve block in emergency department patients with a proximal femoral fracture. 0, absolutely no pain; 10, most extreme pain. Boxes show median and interquartile range, whiskers mark the minimum and maximum (1.5 × lower and upper quartile), dots are outliers. NRS, numeric rating scale. * $p < .001$, ** $p < .001$, *** $p = .03$.

Table 5.4 Influence of relevant factors on absolute pain reduction 30 minutes after ultrasound-guided regional anesthesia

Factors	Mean difference or correlation	95% CI	*p* value
t-test			
Gender (male, female)	−0.03	−1.48, 1.42	.97
Laterality (left, right)	−0.55	−1.95, 0.85	.43
Prehospital analgesics (no, yes)	0.96	−3.56, 5.47	.57
Block type (femoral nerve, FICB)	1.25	−0.32, 2.81	.11
Ropivacaine concentration (0.375%, 0.75%)	−0.13	−1.56, 1.30	.43
One-way ANOVA			
Fracture type (femoral neck, trochanteric, femoral shaft)			.10
Correlation	Pearson's *r*		
Age	−.063		.32
Volume of ropivacaine 0.375%	−.230		.14
Volume of ropivacaine 0.75%	−.078		.33

Mean difference shows the absolute reduction in pain score on a 0-10 numeric rating scale and is without dimension, including 95% confidence interval (CI). A negative difference indicates the pain score reduction is greater in the variable's first value (e.g. male > female). A positive difference indicates the greatest reduction in the second value (e.g. male < female).
FICB, fascia iliaca compartment block.

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Discussion

We showed that, after having received appropriate training, Dutch EPs are able to safely perform UGRA in ED patients presenting with a proximal femoral fracture and severe pain. After 30 and 60 min, mean pain reduction was respectively 3.84 (50.9%) and 4.77 (64.4%). A pain score of 4 or less was reported by 69 and 83.3%, respectively, of the patients. The EPs thought the procedure was easy to perform, and they were able to obtain a good visualization of the relevant anatomy and LA spread. This means that performing a peripheral nerve block is an effective pain relief strategy provided by the very first physician they encounter upon admittance in the hospital.

To date, there are only few similar reports of EPs performing UGRA in the ED. At 30 and 60 min after the nerve block, we found a meaningful pain reduction, respectively, in 70.7 and 80.0% of the patients. We could confirm the results reported by Groot et al. who reported that on a Dutch ED, EP-performed blind FICBs were safe and effective. In 26 of 34 patients (76%), they found a clinically meaningful pain score reduction after 120 min.[19] An explanation for the slightly better and faster pain reduction in the present study might be that we have used an ultrasound-guided technique, compared to their blind FICB. Accurate deposition of the LA in relation to the fascia iliaca, or adjacent to or surrounding the femoral nerve will lead to a more effective and faster effect.

Dochez described the effect of blind FICBs performed by EMS nurses in 100 patients with suspected proximal femoral fractures. After 30 min, they reported a successful block in 96% and median pain scores were reduced from 8 to 3, and on arrival at the ED, 75% had a pain score of 4 or less.[20] Median pain reduction at t = 30 and pain scores of 4 or less were comparable (respectively, 5 and 69.9%).

Gozlan described prehospital EP-performed blind FICBs in 52 patients with femoral fractures and reported a success rate of 94% and pain reduction comparable to Dochez and the present study.[21] Morrison et al. compared standard analgesics with EP-performed ultrasound-guided femoral nerve blocks and found a significant difference in favor of the latter. Baseline NRS was 6.4 in both groups and decreased to 5.3 and 3.5, respectively, after two hours. Unfortunately, they did not report within-subject pain score reduction in the nerve block group.[15]

A study by Beaudoin reported similar results to our study.[17] Thirty-six ED patients with proximal femoral fractures were randomized between a femoral nerve block and conventional analgesia. The median pain score in the nerve block group reduced from a mean NRS of 8 at baseline to 4 after four hours. In the group receiving standard care, the NRS was 8 initially and showed no improvement.[17] Haines et al. described 20 ED ultrasound-guided FICBs performed by six EPs, fellows, and residents. They found a pain reduction from a mean NRS of 7.9 at baseline to 2.05 at 30 min and 1.30 at 120 min.[22]

We showed EPs and EPs in training can be taught to effectively and safely perform UGRA in the ED. In addition, they experienced the procedure to be relatively easy and successful, represented by the high EP-reported scores for success, easiness, visibility of the anatomy, and quality of LA spread. These findings implicate that (Dutch) EPs should consider the introduction of ultrasound-guided regional anesthesia in proximal femoral fracture patients in the ED to provide superior pain management as compared to conventional systemic analgesics. Such a program should preferably be introduced in cooperation with their colleagues from the anesthesiology department. Once a successful UGRA program for these patients is implemented, it can be extended to other indications in need of excellent pain management.

With this project, we followed the recommendation by Wu et al. that anesthesiologists with extensive experience in regional anesthesia should introduce these techniques into settings outside the operating room and in the early treatment phases of trauma patients to provide the benefits of regional anesthesia.[23] Although in our institution, skilled anesthesiologists collaborated with EPs to successfully introduce UGRA in the ED, this approach might not be feasible in other comparable hospitals. EPs must connect with instructors with sufficient skills who are willing and able to invest their time and energy. Nevertheless, superior pain relief should be obtained in trauma patients as early as possible, preferably by the first—prehospital—care provider they encounter.[24] If this journey cannot start at home, adequate pain relief needs to be taken care of by the first care provider they encounter in the hospital.

This study adds to the literature because we took a unique approach in the introduction and execution of these blocks on our ED through a productive collaboration between the two (ED and anesthesiology) departments.

Furthermore, to date, there have been no published reports of effective and safe UGRA in a Dutch ED.

Limitations

This study has several limitations. The observational study design is not optimal to answer the main question. A relatively small number of patients was included based on convenience sampling. The aim was to treat proximal femoral fracture patients with ultrasound-guided nerve blocks as the treatment of choice. Although UGRA was recently introduced in our

ED, its effectiveness has been proven extensively.[8,13,25] To guarantee efficacy and safety of the blocks in the ED setting, anesthesiologists have trained the EPs and supervised the blocks on request. Therefore, we chose not to compare with traditional treatment strategies but to investigate pain reduction within subjects and explore subjective experiences of both health care providers and patients. Another limitation is the increasing amount of missing data at the 30, 60, and 120 min intervals from baseline. This might be caused by high ED work-load, resulting in incompletely filled-out case report forms, but is mainly due to expeditious patient transfer to the ward or the operating room. Also, there is a risk of bias because the EPs and ED nurses who performed the blocks filled out the case report forms themselves. These limitations can be partly justified because the efficacy of these blocks has been proven in general. In the present study, they have been performed in most (78%) cases by at least two physicians (or residents) and an ED nurse all verifying the correct technique.

Conclusions

In conclusion, this study demonstrates that, through close cooperation between EPs and anesthesiologists, after a one-day training (Dutch), EPs can learn to safely perform ultrasound-guided nerve blocks in proximal femoral fracture patients in the ED, resulting in effective acute pain relief.

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5

Part III

Ultrasonography in a Dutch helicopter emergency medical service

Chapter 6

Prehospital chest ultrasound by a Dutch helicopter emergency medical service

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Abstract

Background

Due to advancements in technology, the use of a portable ultrasound (US) machine in the out-of-hospital setting is increasingly feasible. It has diagnostic and therapeutic advantages and may improve the management and treatment of patients. It can be used in-flight and can be easily taught to flight clinicians who have little previous experience with this modality.

Study Objectives

The aim of this study was to evaluate the impact of ultrasound chest examinations on the care of patients treated by a helicopter emergency medical service (HEMS).

Methods

Since 2007, portable US has been used by the HEMS of Nijmegen, the Netherlands. Data on every air medical flight are routinely collected in a database. Every portable US examination of the chest performed between 2007 and 2010 was reviewed for this study. Data on patient characteristics, properties of US examinations, US diagnoses, and impact on medical treatment were collected and analyzed.

Results

Of a total of 2572 patients, 326 portable US examinations of the chest were performed in 281 (11%) patients. The mean duration of a portable US examination was 2.77 (*SD* 1.30) min, and the duration decreased over time. After the US examination, the plan for treatment changed in 60 (21%) patients. In 10 patients (4%) the plan to place a chest tube was abandoned. In ten patients (4%) the initially selected destination for definitive care changed, and it changed to a lower-level hospital more often than to a higher-level one. In nine patients (3%), cardiopulmonary resuscitation was stopped and in 31 patients there were other changes.

Conclusions

Out-of-hospital US examinations may alter and improve treatment decisions and destinations for definitive care.

Introduction

Due to technological advancements and miniaturization in the field of microprocessors, batteries, and digital screens, the use of portable ultrasound (US) machines is rapidly increasing in the out-of-hospital setting.[1] Different authors have shown that the use of prehospital US can yield both diagnostic and therapeutic advantages. It does not delay patient treatment, and its performance is feasible and safe during helicopter transport.[2–4] The use of prehospital US in the Netherlands was first documented in 2010 by Gerritse.[5]

Prehospital US examinations are often performed by physicians who are relatively inexperienced in the use of US, compared to radiologists. The recognition of pathologic conditions in a trauma patient seems to be easily taught to physicians. This makes it a suitable diagnostic tool for use out-of-hospital.[6–9]

The objective of this study was to evaluate the impact of US on the therapeutic plan for patients treated by a Helicopter Emergency Medical Service (HEMS) team. This is a retrospective analysis of four years of data from the Nijmegen, the Netherlands HEMS on portable chest US examinations in prehospital emergencies.

6

Materials and methods

The Nijmegen HEMS is one of four Dutch HEMS. It services an area of 10,088 square kilometers (3895 square miles) in the eastern part of the Netherlands, and a population of 4.5 million.[10] On average, there are 1400 flights undertaken every year, 45% of which are cancelled while in flight.[11] Paramedics arrive at the scene by ambulance before the HEMS arrives in most cases. They are authorized to assess the situation and to consequently cancel the helicopter.

The Nijmegen HEMS started using a portable US machine in January of 2007. Thirteen (of 14) physicians working at the HEMS perform US examinations of the chest and abdomen according to the standardized method of the Polytrauma Rapid Echo-Evaluation Program (Programme Rapide d'Échographie d'un Polytraumatisé [PREP]; École Internationale d'Échographie, Nîmes, France). This method is comparable to the extended focused assessment with sonography for trauma (eFAST) protocol complemented with measurements of the abdominal aorta. The use of portable chest US for reasons other than cardiac ones is relatively new. The PREP method makes use of an artifact that occurs when, in the absence of a pneumothorax, sound waves reflect off of the parietal and visceral pleura. These two layers can be observed moving in relation to each other. These so-called *comet-tail artifacts* and *lung sliding sign* demonstrate that the two pleural layers lie together, and this helps to exclude the existence of a pneumothorax.[12,13]

The PREP method is specifically designed to be used out of hospital or in the Emergency Department (ED). Five US windows are defined and have to be sequentially scanned looking for abnormal artifacts, fluid-air interfaces, and air or fluid collections in the chest and abdomen. The five windows in order of examination are: right lung, liver, and right kidney; left lung, spleen, and left kidney; uterus, bladder, and recto-uterine pouch; heart and pericardium; and abdominal aorta. Just like the eFAST, a PREP examination has to be completed within three minutes.

We use a portable US machine weighing 3.5 kg (MicroMaxx®, Fujifilm SonoSite Inc., Bothell, WA, USA) equipped with a 5–1 MHz broadband phased-array transducer.

For every scramble (we prefer this military-derived term to indicate the typical swift dispatch of the HEMS), a large amount of data are collected by the HEMS physicians in a custom-made database.

Data were selected from the database of all scrambles between January 1, 2007 and June 1, 2010 in which one or more US examinations of the chest and its contents were performed. The following data were selected: patient characteristics (gender, age, and estimated weight), US examination characteristics (performing physician, its timing [on arrival at the patient, during treatment, before departure, during transport, or on arrival at the hospital], duration, quality of imaging [good, moderate, or poor], specific location [thorax, pericardium, or heart], findings per location), and diagnosis based on US examination. Also, the impact of the US examination on treatment decisions was recorded.

The results of chest X-ray study (CXR) and computed tomography (CT) examinations of the patients who were transported to our hospital were recorded to calculate sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of prehospital portable US for the diagnosis of pneumothorax. CT scan results were used as a reference.

Comparison of quality of imaging and body weight was done only in patients aged 18 years and older because their body weight correlates better with body mass index (BMI) than in younger patients.[14]

Data were collected in an Excel spreadsheet (Microsoft Corp., Redmond, WA, USA) and

analyzed using IBM SPSS Statistics for Windows, version 19.0 (IBM Corp., Armonk, NY, USA). Differences in duration of the examination between years were analyzed using one-way analysis of variance (ANOVA). Differences in quality of imaging for different body weights were analyzed using the chi-squared test. A p-value < .05 was considered statistically significant. The medical ethics review board of our institution determined our research to be exempt from review.

Results

Between January 1, 2007 and June 1, 2010, 2572 patients were treated by our HEMS. In 281 patients (11%), 326 portable US examinations of the chest were performed during 275 scrambles. Sometimes more than one patient was treated during one scramble and some patients underwent more than one US examination.

There were 39 US examinations performed in 31 patients receiving primary cardiopulmonary resuscitation (CPR). There were 287 US examinations in 250 trauma patients. The number of examinations per patient was 1.26 for CPR and 1.15 for trauma patients (difference is not significant).

The mean age was 38 years (median 36), with a mode of 22. There was a relatively high incidence of US examinations before the age of 4 years. Seven children were younger than 1 year,

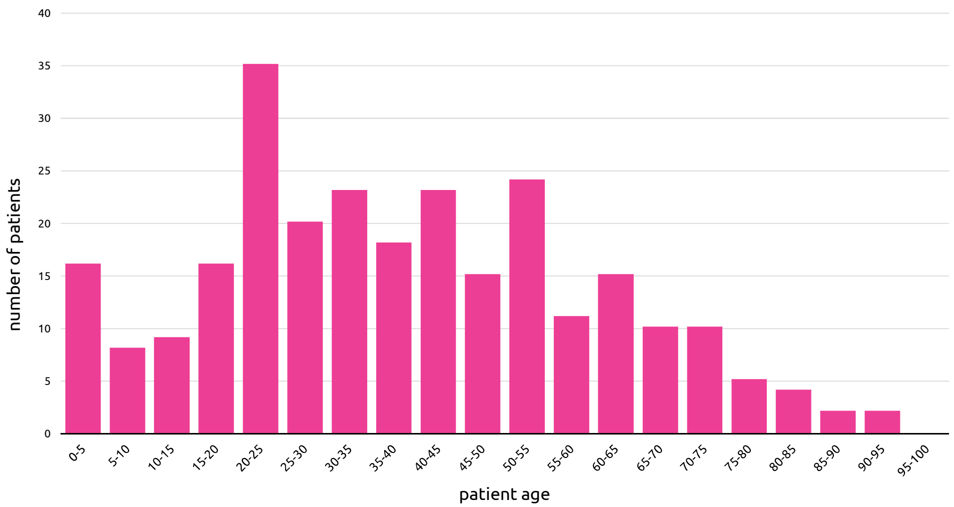

Figure 6.1 Age distrubution of all patients who underwent a chest ultrasound examination

one of whom was newborn. The age distribution is shown in Figure 6.1. The male:female ratio was 3.6:1. The male:female ratio of the total 2572 patients treated was 2.7:1.

The distribution of timing of the US examination is shown in Table 6.1. The mean duration of one US examination was 2.77 min (standard deviation [*SD*] 1.30; range 0–10 min). In 2009 and 2010, the last two years of the four-year study period, the mean duration was shorter than it was in the first two years: 2.26 (*SD* 1.14) and 2.37 (*SD* 0.86) min, respectively. In 2007 and 2008, the mean duration was 3.02 (*SD* 1.38) and 3.43 (*SD* 1.22) min, respectively. One-way ANOVA analysis demonstrated a significant difference between the four years ($p < .001$).

The quality of imaging was rated good in 179 (55%) of the US examinations. It was rated moderate and poor in 82 (25%) and 14 (4%), respectively. Quality was not rated in the remaining

Table 6.1 Timing of the ultrasound examination

Timing	*n* (%)
On arrival at the patient	70 (21)
During treatment	70 (21)
Before departure	59 (18)
During transport	119 (37)
On arrival at the hospital	8 (2)

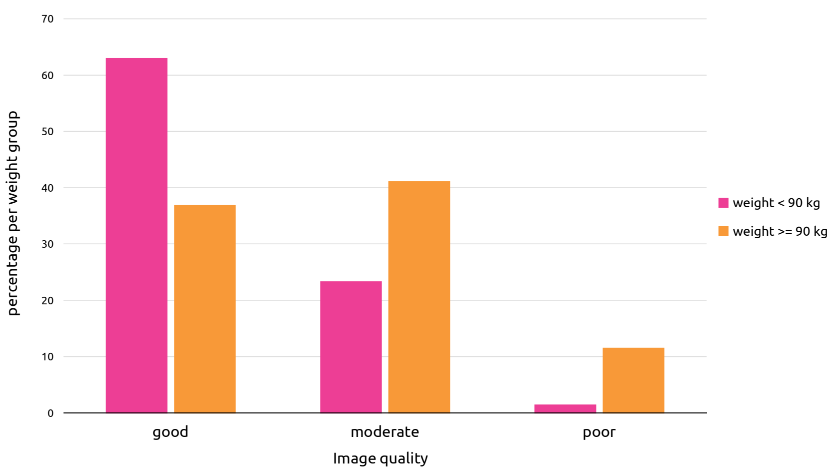

Figure 6.2 Image quality distribution per weight group

The population was divided into two groups based on their body weight. For both weight groups, the frequency of good, moderate, or poor ultrasound image quality is shown.

51 (16%) examinations. Quality of imaging depended on body weight as shown in Figure 6.2. The differences are statistically significant (chi-squared $p < 0.001$).

For all 326 US examinations, a cardiac or pulmonary diagnosis was recorded as shown in Table 6.2. The cardiac US diagnoses are shown separately for trauma patients and for patients in whom there was primary CPR.

Of the 59 (21%) patients transported to our hospital, a CXR and a CT scan were performed. Sensitivity and specificity of prehospital US for pneumothorax were 38% and 97%, respectively. Positive and negative predictive values were 90% and 69%, respectively. In the 15 patients for whom US examinations were false negative, there were false-negative CXRs in 12 cases. Positive and negative test results are shown in Table 6.3.

The diagnosis of hemothorax was specifically excluded six times and confirmed only once by US examination. There were no false-positive and no false-negative US results.

Table 6.2 Ultrasound examination diagnoses and observations

Injury	Trauma patient *n* (%)	Primary CPR *n* (%)	Total *n* (%)
Cardiac			
Asystole	26 (8)	22 (7)	48 (15)
Poor myocardial contractility	9 (3)	8 (2)	17 (5)
Poor ventricular filling	9 (3)	3 (1)	12 (4)
Pulmonary			
Pneumothorax	25 (9)	–	25 (9)
Hemothorax	2 (1)	–	2 (1)
Pulmonary contusion	2 (1)	–	2 (1)

CPR, cardiopulmonary resuscitation.

Table 6.3 Comparison of ultrasound examination with CT for pneumothorax in patients transported to the Radboud university medical center

Test result	CT +	CT –	Total
US +	9	1	10
US –	15	34	49
Total	24	35	59

CT, computed tomography; +, positive test result; –, negative test result.

The HEMS physicians stated that treatment decisions changed in 60 cases (21%) due to information obtained by the US examination. In 9 of 60 patients, the physician decided to stop all treatment based on the US imaging of the heart. The strategy towards administering intravascular fluids changed in 6 patients. In total, 24 chest tubes were inserted. The decision to insert a chest tube or, on the other hand, to refrain from inserting one changed in 13 cases. Of the 15 false-negative US examinations for pneumothorax, no decision to insert a chest tube before (or after) US was made.

In 10 cases, the destination hospital changed. The destination changed more often to a lower-level hospital than to a Level I trauma center. The relative number of treatment decision changes does not differ between years in our study. All changes are displayed in Table 6.4.

Table 6.4 Change in treatment decisions as a result of ultrasound examination

Change in treatment decision	Trauma patient	Primary CPR	Total
Cardiac			
Initiate inotropic medication	2 (3)	–	2 (3)
Stop resuscitation	4 (7)	5 (8)	9 (15)
More intravascular fluids	2 (3)	–	2 (3)
Less intravascular fluids	4 (7)	–	4 (7)
Pulmonary			
Reposition endotracheal tube	1 (2)	–	1 (2)
Refrain from inserting a chest tube	10 (17)	–	10 (17)
Insert chest tube	3 (5)	–	3 (5)
Other			
Change destination	10 (17)	–	10 (17)
to a hospital (instead of none)	1		1
to a lower level hospital	6		6
to a level 1 trauma center	3		3
Transport	4 (7)	–	4 (7)
No physician needed	3		3
Not by helicopter	1		1
Order preparations	4 (7)	–	4 (7)
Prepare operating room	2		2
Prepare blood transfusion at ED	1		1
Personal call to trauma surgeon	1		1
Total			60

Percentages of the total number of changes in parentheses; dash, no occurrences.
CPR, cardiopulmonary resuscitation; ED, emergency department

Discussion

US is used increasingly in the prehospital setting, and its value in this context seems promising. There is increasing emphasis on US training of physicians working in Emergency Medicine.[6–9] With an increasing number of trained physicians using US in the field, its added value may become clearer. The value of US on its own already has been established.

Blaivas showed in 176 patients that non-portable US for pneumothorax has a good sensitivity and specificity (98.1% and 99.2%, respectively) and similar PPV and NPV.[15] Nagarsheth and Kurek showed comparable results.[16] US can therefore be said to reliably detect and exclude the presence of pneumothorax. In our study, the sensitivity and NPV are not so high due to a large number of false negatives.

An explanation could be that we use US in the prehospital setting where it is more difficult to interpret the US images due to difficult access to the chest, time pressure, low ambient light, and other distractions. Furthermore, the HEMS physicians have different levels of experience and the screen is smaller and of inferior quality compared to non-portable US machines.

Another factor that may contribute to the low sensitivity and NPV found in this study is the fact that we recorded CT scans that showed a minimal anterior pneumothorax as a positive test result. This may be the cause of the large number of false-negative examinations in corresponding US and CXR examinations. Furthermore, a pneumothorax can develop in a short period of time, even after it has been properly ruled out by US. This is especially true in patients who are intubated and ventilated with positive airway pressure.

Our results show a high incidence of US use in children under the age of four years. Gerritse showed that our HEMS scrambles relatively often for young children and that these flights are cancelled less often than flights for adult victims.[17] Reasons for dispatching the HEMS for children that Gerritse found included hypovolemic shock caused by diarrhea or reduced intake, child abuse, sudden infant death syndrome, asphyxia at birth, and trauma around the home. There is a low threshold for HEMS physicians to perform an US examination during resuscitation of children. The US can provide sufficient information to decide to stop CPR, and additionally, it provides images to allow for a clear explanation to parents or bystanders why CPR was stopped.

The quality of imaging is reduced by an increase in body weight in adults. Due to the design of our database, there was no BMI available, and we cannot determine if the recorded imaging quality refers to chest or abdominal US or both.

According to some authors, a structured US examination according to the FAST method must not take longer than 3 minutes.[4,18,19] The PREP method we use is comparable to the FAST and dictates that an examination is to be completed in under 3 min. The average duration in our study was 2.77 min with a range of 0–10 min. The time it took the physician to complete an examination decreased in 2009 and 2010 compared to the two previous years. This is likely a learning effect. Within our HEMS there were two enthusiastic physicians who used the US machine and were PREP/eFAST-trained before we started using US in 2007. As time progressed, all HEMS physicians became trained and experienced in using US in general and our portable US machine in particular, possibly contributing to a faster US examination.

The time an examination requires is not always so important. US is often used during transport of a patient to the hospital. This causes no delay because the patient is already underway, while providing the physician with additional information.

That prehospital US can change treatment decisions was shown by Walcher.[18] They studied the use of prehospital US with blunt abdominal trauma in a German prehospital setting and showed that US yielded a change of prehospital therapy or management in 30% of the patients and the choice for the admitting hospital was changed in 22%.[18] We found that US of the chest changed these decisions in 21% and 4% of our patients, respectively. In general, German trauma victims are more often transported for a second time to a Level I trauma center after primary assessment and treatment has been carried out at a lower-level hospital.[20] This approach is different from the way prehospital medical care is organized in the Netherlands.

We diagnosed a pneumothorax in 25 patients, whereas we found a hemothorax in only 2. A hemothorax is associated more often with penetrating injury or with injuries associated with a high-energy trauma mechanism. In patients suffering hemothorax, it is perhaps better to omit the US examination and choose to immediately insert a chest tube and transport them to the nearest suitable hospital.

Due to results of previous studies, our findings, and the useful information that can be gleaned from US examinations, none of the PREP-trained HEMS physicians will scramble without the portable US unit anymore.

Limitations

Due to the retrospective nature of this study, some data are missing. Sometimes when the US diagnosis of asystole was recorded, it was not clear whether CPR stopped or continued as a result. Furthermore, when CPR was stopped, it was not always clear if US influenced this decision. Also, the database allowed for only one treatment change to be recorded for every US examination, although more than one change could be possible. The authors speculate that the role that US plays in the prehospital setting is much greater than the number of changes in treatment decisions we found in this retrospective study.

Another limitation is the fact that data were entered in the database after completion of a scramble. There was no registration on-scene. This may mean that some data are less accurate than they would be with a more objective registration.

In the 326 US examinations of the chest, every detail was not always recorded. During CPR, the cardiac findings were recorded, but any pulmonary details were often omitted.

Due to the design of this study, we could not definitively confirm by follow-up data if the change in treatment decisions concerning chest tubes and transport destinations were correct.

Conclusion

A portable US examination is used, in addition to historytaking and physical examination, in the prehospital setting with increasing frequency. In our region this has led to a decrease in the time needed for an US examination.

High sensitivity, specificity, PPV, and NPV of US allow physicians to make an early and accurate diagnosis, which can lead to changes in preliminary treatment decisions, although this can be influenced by many factors. Image quality was influenced by body weight.

Fewer chest tubes than planned were inserted after US was performed, and so a US examination reduced unnecessary invasive treatments. More patients were transported to a lower-level ED, and fewer patients to a Level I trauma center, compared to our intention before the US examination.

Prospective studies with patient follow-up are needed to determine the value of prehospital US examination performed by a HEMS operating in the Dutch health care system. It must be further elucidated whether US is truly a useful addition in the treatment and management of outof- hospital emergencies.

Acknowledgements

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Chapter 7

Abdominal prehospital ultrasound impacts treatment decisions in a Dutch helicopter emergency medical service

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Abstract

Objective:

To determine the impact of abdominal prehospital ultrasound (PHUS) on patient care in a Dutch physician-staffed helicopter emergency medical service (HEMS) and to determine its diagnostic performance.

Methods

We conducted a retrospective analysis of abdominal ultrasound examinations performed by the HEMS of Nijmegen, the Netherlands, from January 2007 until December 2016. Data including patient demographics, type of incident, abdominal ultrasound findings, impact on treatment decisions, and the physicians' narrative report were retrieved from the HEMS database and analyzed. PHUS diagnostic performance was compared with computed tomography scan or laparotomy.

Results

Of 17077 recorded scrambles and 8699 patients treated, 1583 underwent 1631 abdominal ultrasound examinations. After eliminating missing data, 251 impacts on treatment in 194 out of 1539 PHUS examinations were identified (12.6%, 95% CI: 10.9, 14.3). This affected 188 out of 1495 (12.6%) patients. The four main categories of treatment decisions impacted by PHUS were: information provided to the destination hospital (45.4%); mode of transportation (23.5%); choice of destination hospital (13.1%) and fluid management (11.6%). Sensitivity of prehospital abdominal ultrasound for hemoperitoneum was 31.3%, specificity 96.7%, and accuracy 82.1%.

Conclusions

Abdominal PHUS in our setting impacts treatment decisions significantly. Therefore, it is a valuable tool in the Dutch HEMS setting, and probably beyond.

Introduction

The use of diagnostic ultrasound is becoming ever more common and plays an important part in emergency medicine worldwide.[1] As a reliable, quick, low cost, and harmless diagnostic tool for emergency care providers, its relevance and utility in emergency medicine are highly regarded.[2,3] This is especially true when acute intra-abdominal hemorrhage is suspected, associated with blunt abdominal trauma resulting from prevalent trauma mechanisms such as falls from heights and road traffic accidents (RTA).[4] It is a significant factor for mortality after trauma and requires quick intervention since treatment delay decreases survival.[5,6] The development and introduction of portable ultrasound devices reduced this delay, and the feasibility and utility of prehospital ultrasound (PHUS) in prehospital emergency medicine are demonstrated.[7–9]

PHUS has been introduced in (Helicopter) Emergency Medical Services ([H]EMS) and impacts prehospital patient care such as a switch to scoop-and-run tactics, mode of transport and choice of destination hospital.[10–12] Although some research on the subject is available, recent reviews conclude that the positive contribution of abdominal (PH)US is feeble.[13,14] Prehospital health care providers in some parts of the world still refrain from PHUS because of an unconvincing cost-benefit analysis.[15] Research on ultrasound in prehospital emergency medicine was recently appointed to be a top five priority by a European research collaboration.[16]

Many studies on PHUS in trauma patients include both thoracic and abdominal injury. Our previous study showed a positive contribution of PHUS in chest injuries.[11] Studies focusing on abdominal injuries are scarce. The objective of this study is to determine the impact of abdominal PHUS on patient care in our region.

7

Methods

Study setting

The Nijmegen HEMS, a department of the Radboud university medical center (Radboudumc), is one of four HEMS in the Netherlands. It services the largely rural eastern part of the country and cooperates with German emergency services. An area is covered of 10,088 square kilometers (3,895 square miles) and roughly 4.5 million people. The Dutch HEMS teams consist of a physician (anesthesiologist or trauma surgeon), an emergency care nurse (HEMS Crew Member) and a pilot. The service is supplementary to a network of paramedic-staffed ground ambulances and is deployed by the regional dispatch center based on either the emergency call or on the paramedic's request, resulting in over 17,000 scrambles within the study period (2007–2016). Most often, the ambulance paramedics are the first to arrive on-scene and whenever patients are found to be vitally stable, deceased, or not present, HEMS scrambles are canceled in flight in consultation with the HEMS physician. Likewise, it can be decided not to wait but to transport immediately to the nearest appropriate hospital.

All PHUS examinations are performed by HEMS physicians according to the Polytrauma Rapid Echo-Evaluation Program (PREP), a French protocol similar to the Extended Focused Assessment with Sonography for Trauma (eFAST). All physicians have successfully completed a two-day PREP course that consists of lectures, and mainly hands-on training. During the course, all participants perform at least 20 PREP examinations on each other and on peritoneal dialysis patients (having free intraperitoneal fluid). The goal is expeditious screening of the chest, heart, pericardium, and abdomen, in under three minutes.

During the study period, three ultrasound devices were used: MicroMaxx®, NanoMaxx®, and M-Turbo® (Fujifilm SonoSite Inc., Bothell, WA, USA), all equipped with a 5–1 MHz broadband phased-array transducer. For every scramble and every patient, physicians create an electronic medical record (EMR) in the custom-built HEMS database. This includes patient characteristics, trauma mechanism, working diagnosis, mode of transport and destination before PHUS, impact of PHUS on treatment plan, and a concise narrative report.

Design

We conducted a retrospective analysis of every patient in whom an abdominal PHUS examination was performed by the Nijmegen HEMS in the period from the 1st of January 2007 until the 31st of December 2016. The regional ethics review board of Arnhem/Nijmegen approved our study and decided it to be exempt from further formal ethical review (2017-3123).

The primary objective was to identify treatment impacted by abdominal PHUS. Secondary objectives were to identify trauma mechanisms and illnesses for which abdominal PHUS was used and to calculate the diagnostic performance of PHUS.

Data collection and analysis

From the HEMS database, all patients who underwent at least one abdominal PHUS examination were selected. Extracted data included patient demographics (sex, age, and estimated weight), trauma mechanism or illness, PHUS-specific notes (including PHUS timing, abdominal findings, and impact on patient care) and the physicians' narrative report. This data set was imported into a secured Castor database (Ciwit B.V., Amsterdam, the Netherlands) that is compliant with Good Clinical Practice guidelines and allows for audit trails.

In the HEMS database, it is allowed, but not required, to add PHUS-specific notes and its impact on treatment. Alternatively, PHUS results and impact on treatment may be included in the narrative report. Whenever PHUS-specific notes were missing, two researchers (JH and RK) independently reviewed the EMR, including all available data, notes, and the narrative report, to identify any impacts on patient treatment. Whenever individual judgments differed between researchers, the case was discussed using a strict set of pre-defined criteria. Specific impacts after PHUS were scored and categorized. Questionable cases were again independently scored and subsequently discussed.

In many cases, a complete sonographic examination was performed, also including the chest and pericardium. Impacted treatment as a result of PHUS of other regions than the abdomen was excluded.

To calculate diagnostic performance of PHUS, hospital EMRs of every patient transported to our trauma center (Radboudumc) were reviewed. CT scan and laparotomy reports were scrutinized for the presence of free abdominal fluid while being blinded to the PHUS results.

To look for a difference of the timing of PHUS on its diagnostic performance two groups were defined: an early group (PHUS upon arrival or during treatment) and a late group (PHUS during transport or upon arrival at the hospital). Since no exact PHUS times were recorded in the database, a fifth category (just before departure) could both qualify as an early or late timing and was therefore not included in either group.

The duration of patient contact was the interval between HEMS team arrival on-scene and the moment patient care was transferred to either the ambulance service or the emergency department.

The data were analyzed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used for impacted treatment, incidence of trauma mechanisms and illnesses, and PHUS diagnostic performance. Normally distributed data are reported as mean ± standard deviation (*SD*), data with a skewed distribution are reported as median with an interquartile range (IQR). The interquartile range (IQR) was calculated using Tukey's hinge technique. Pearson's chi-squared test was used to test for differences in trauma mechanisms and illnesses between the Radboudumc and non-Radboudumc group. Statistical significance was considered at $p < .05$.

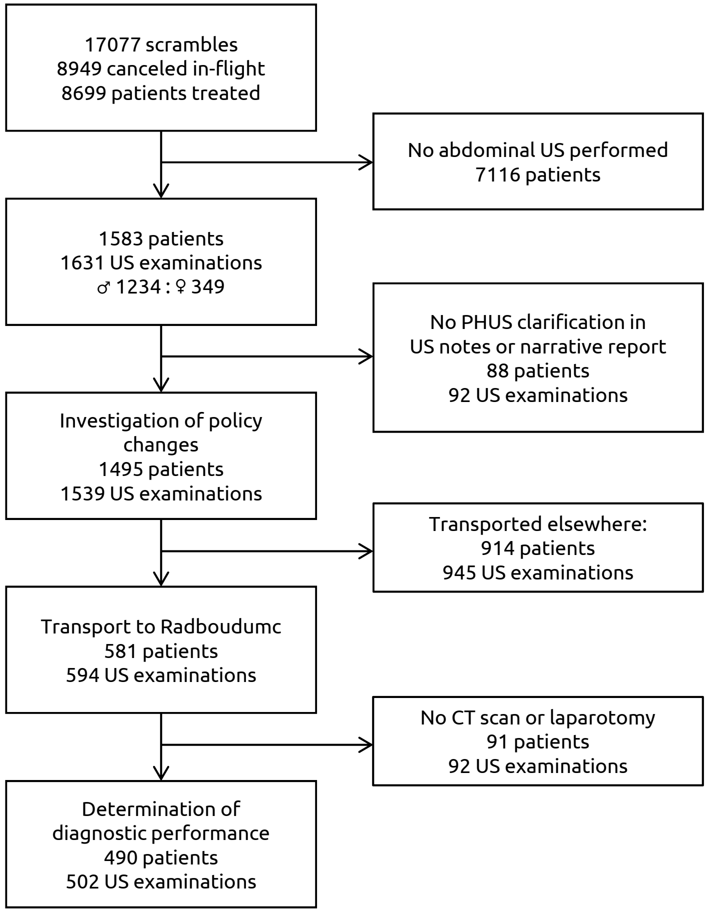

Figure 7.1 CONSORT diagram of the study population

CT, computed tomography; PHUS, prehospital ultrasonography; US, ultrasound.

Results

The study Consort diagram is shown in Figure 7.1. In the 10-year study period, 1583 patients underwent 1631 abdominal PHUS examinations since some patients were examined twice. After excluding missing data, 1495 patients (1539 US examinations) were analyzed. In 970 cases, PHUS-specific notes were missing in the database and were independently reviewed as described above. Inter-rater reliability was 87.5%, and eventually, consensus was reached in all cases.

The mean age was 40.5 years (median 39, mode 21), and 29.8% were under 25. Young (male) adults were overrepresented. Demographics are displayed in Table 7.1.

Table 7.1 Demographics

Demographics	*n* (%)	Mean ± *SD*	Median (IQR)	Range
Age (years)	1558 (98.4)	40.5 ± 20.1	39 (23–54)	0–93
Gender				
Male	1234 (78)			
Female	349 (22)			
Estimated weight (kg)	1315 (83.1)	78.8 ± 18.6	80 (70–90)	5–150
Total	**1583 (100)**			

SD, standard deviation; IQR, interquartile range.

Primary outcome

In total 251 impacts on treatment were found in 194 of 1539 PHUS examinations (12.6%, 95% CI: 10.9, 14.3), concerning 188 of 1495 patients (12.6%). PHUS most frequently impacted: information provided to the destination hospital (45.4%); mode of transportation (23.5%); choice of destination hospital (13.1%) and fluid management (11.6%). Affected treatment is displayed in Table 7.2.

We identified a scale down subgroup of PHUS examinations that impacted or supported decisions in which patients were either transferred to a lower level hospital or were not escorted by a physician. This subgroup includes 73 of 251 (29.1%) decisions in 62 of 1539 examinations (4.0%) and 62 of 1495 patients (4.1%).

Table 7.2 Decisions impacted by abdominal prehospital ultrasound

Type of impacted treatment	*n* (%)
Fluid management	29 (11.6)
Aggressive (including packed red cells and hypertonic saline)	20 (8.0)
Restrictive	9 (3.6)
Notification to the receiving hospital	114 (45.4)
Trauma team consultation/preparation	19 (7.6)
Packed red blood cells preparation	15 (6.0)
Additional imaging requested	80 (31.9)
Scoop & run tactics	5 (2.0)
Mode of transportation	59 (23.5)
By ambulance, not escorted by physician	53 (21.1)
By ambulance, escorted by physician	2 (0.8)
Vehicle change (helicopter vs ambulance)	4 (1.6)
Choice of destination hospital	33 (13.1)
To a lower-level hospital	20 (8.0)
To a higher-level hospital (trauma center)	13 (5.2)
Medication administration	2 (0.8)
Unknown	9 (3.6)
Total	**251 (100)**

Note: impact on medication consisted of the administration of phenylephrine (vasoconstrictor).

Secondary outcomes

The trauma mechanisms and illnesses for which PHUS was performed are shown in Table 7.3. An overview of trauma mechanisms and illnesses in the entire base population treated in the 10-year study period is displayed in Table 7.4 and Figure 7.2. The main trauma mechanisms are RTAs (68.3%) and falls from heights (16.7%). No significant difference in trauma mechanisms or illnesses between the Radboudumc and non-Radboudumc subpopulations was found (p = .374). Car and cargo truck drivers suffering accidents did not wear their safety belts in 577 (48.2%) of the cases.

Sensitivity and specificity of PHUS for free abdominal fluid was 31.3% and 96.7% respectively. Positive predictive value and negative predictive value were 72.9% and 83.0%. Diagnostic accuracy was 82.1%. In 39 of 53 cases when patient care was transferred to ground ambulances, data on follow-up was available in the HEMS database. In 39 (100%), in-hospital imaging results matched our PHUS findings (1 true positive and 38 true negatives).

Table 7.3 Trauma mechanisms and illnesses

mechanism or illness	Radboudumc *n* (%)	Non-Radboudumc *n* (%)	Total *n* (%)
Road traffic accident	402 (69.2)	679 (67.8)	1081 (68.3)
Fall from height	94 (16.7)	170 (17.0)	264 (16.7)
Entrapment (no traffic accident)	17 (2.9)	40 (4.0)	57 (3.6)
Stab or firearm incident	19 (3.3)	18 (1.8)	37 (2.3)
Equestrian accident	11 (1.9)	22 (2.2)	33 (2.1)
Train accident	4 (0.7)	6 (0.6)	10 (0.6)
Aircraft accident	0 (0)	1 (0.1)	1 (0.1)
Drowning	0 (0)	3 (0.3)	3 (0.2)
Suffocation	1 (0.2)	0 (0.0)	1 (0.1)
General illness	13 (2.2)	13 (1.3)	26 (1.6)
Cardiopulmonary resuscitation	7 (1.2)	18 (1.8)	25 (1.6)
Intoxication	0 (0)	2 (0.2)	2 (0.1)
Other incidents	11 (1.9)	27 (2.7)	38 (2.4)
Unknown cause	2 (0.3)	3 (0.3)	5 (0.3)
Total	**581 (100)**	**1002(100)**	**1583 (100)**

Table 7.4 Trauma mechanisms and illnesses in study subpopulation related to the base population

mechanism or illness	Study population *n* (%)	Base population *n* (%)	Relative (%)
Road traffic accident	1081 (68.3)	4175 (48.0)	25.9
Fall from height	264 (16.7)	1341 (15.4)	19.7
Entrapment (no traffic accident)	57 (3.6)	248 (2.9)	23.0
Stab or firearm incident	37 (2.3)	201 (2.3)	18.4
Equestrian accident	33 (2.1)	154 (1.8)	21.4
Train accident	10 (0.6)	68 (0.8)	14.7
Aircraft accident	1 (0.1)	10 (0.1)	10.0
Drowning	3 (0.2)	168 (1.9)	1.8
Suffocation	1 (0.1)	178 (2.0)	0.6
General illness	26 (1.6)	964 (11.1)	2.7
Cardiopulmonary resuscitation	25 (1.6)	492 (5.7)	5.1
Intoxication	2 (0.1)	94 (1.1)	2.1
Other incidents	38 (2.4)	277 (3.2)	13.7
Unknown cause	5 (0.3)	55 (0.6)	9.1
Total	**1583 (100)**	**8699 (100)**	**18.2**

Note: the information in the study population column is identical to the rightmost column in Table 7.3. These data are displayed in Figure 7.2.

7

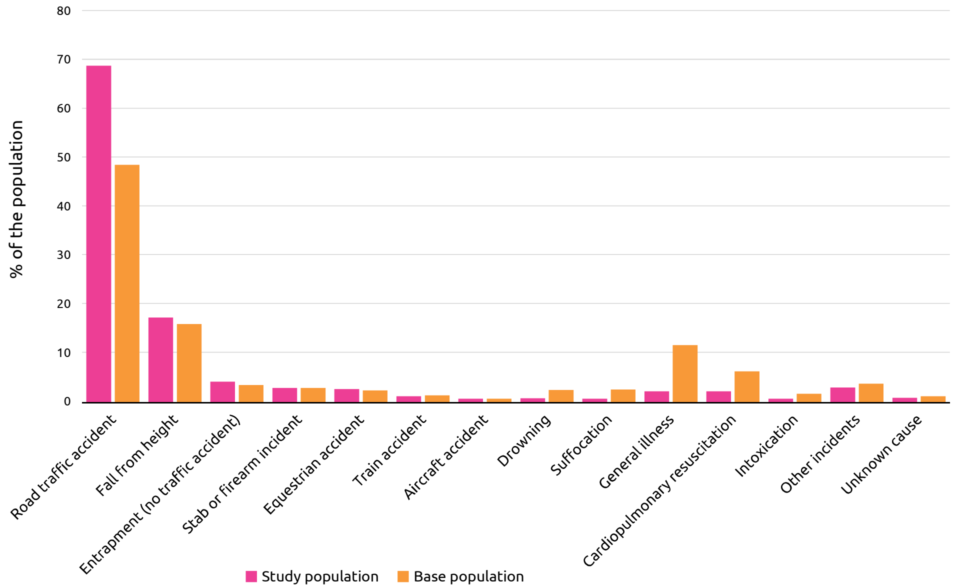

Figure 7.2 The distribution of trauma mechanisms and illnesses in the entire base population and study population

The five categories of PHUS timings are displayed in Table 7.5. Sensitivity in the early and the late group was respectively 26.9% and 31.8%. Specificity increased from 94.6% to 97.9%. Both differences in sensitivity and specificity where the time interval between (late) PHUS and in-hospital CT or laparotomy is shortest, were not statistically significant (p = .65, p = .12). PHUS is compared to CT or laparotomy for the two groups in Table 7.6.

The mean duration of patient contact was 38.9 (± 17.8) minutes. When the patients were not escorted by the physician, the mean and median were 21.9 (± 13.3) and 19.0 (13–28) minutes, when the patients were escorted respectively 42.6 (± 16.5) and 41.0 (32–50) minutes.

Table 7.5 Timing of ultrasound examinations

Timing of ultrasound examination	Radboudumc *n* (%)	Total *n* (%)
Immediately upon arrival	36 (6.1)	131 (8.0)
During treatment	107 (18.0)	321 (19.7)
Before departure to hospital	97 (16.3)	304 (18.6)
During transport	353 (59.4)	868 (53.2)
Upon arrival at hospital	1 (0.2)	7 (0.4)
Total	**594 (100)**	**1631 (100)**

Table 7.6 PHUS diagnostic performance for free abdominal fluid, early and late group compared

	PHUS	CT scan or laparotomy, *n* (%) +	–	
	+	7 (26.9)	5 (5.4)	12 (58.3% = PPV)
Early group[a]	–	19 (73.1)	88 (94.6)	107 (82.2% = NPV)
	Total	**26 (100)**	**93 (100)**	**119**
	+	21 (31.8)	5 (2.1)	26 (80.8% = PPV)
Late group[b]	–	45 (68.2)	232 (97.9)	277 (83.8 % = NPV)
	Total	**66 (100)**	**236 (100)**	**302**

PHUS positive (+) or negative (–) for free abdominal fluid, compared to CT scan or laparotomy.
PHUS, prehospital ultrasound; CT, computed tomography
PPV, positive predictive value; NPV, negative predictive value.

a. Combined ultrasound examinations performed upon arrival and during treatment on-scene
b. Ultrasound examinations performed during transport.

7

Discussion

In 12.6% of the patients an abdominal PHUS examination impacts treatment. This suggests that PHUS might change treatment decisions in patients suspected of abdominal injuries. In our opinion, this reaffirms the use of ultrasound even with a low likelihood of abdominal injury. In our HEMS, abdominal PHUS is most often performed after RTAs and falls from heights, both associated with blunt abdominal trauma. We found a high specificity and accuracy for free abdominal fluid, but low sensitivity. The implication of the low sensitivity of PHUS (31.3%) might be that, despite a negative PHUS, health care providers should be vigilant for any previously undetected intraperitoneal hemorrhage.

The present study confirms previous research that concludes PHUS alters or at least supports treatment but found a lower proportion of affected patient care.[10,12] In a prospective study, Walcher demonstrated that PHUS changed patient treatment in 30%, and choice of destination hospital in 22%.[10] They specifically included patients suspected of blunt abdominal trauma. This might indicate that PHUS has more impact when the a priori chance of abdominal hemorrhage is high. O'Dochartaigh found a higher amount in chest and abdominal US (23–57% depending on the mission type and medical crew composition, 32% overall).[12] In this retrospective analysis, they looked for supported treatment instead of specific alterations. Similar to our previous study, it appears that treatment decisions are influenced more frequently in patients with chest injuries, probably because of the availability of effective treatment options such as thoracostomy and chest drain placement.[11] We chose a retrospective study design with a database not designed for the study. HEMS physicians fill out the database after a scramble, therefore recall bias might occur and record keeping may be less accurate. Our study population differs; every patient who underwent abdominal ultrasound was included.

The diagnostic performance we found confirms the results of Blackbourne's study in an emergency room setting.[2] We found a sensitivity and specificity of respectively 31.3% and 96.7% that correspond to their respective values of 31.1% and 99.8%. Sensitivity is low and possibly due to factors such as the prehospital setting with its numerous detrimental environmental factors, high stress, time pressure, and relatively short time intervals between the incident and PHUS and the far larger interval after which in-hospital diagnostics are performed. The restricted sonographic view of the pelvis and Douglas' pouch due to pelvic stabilization devices provides another possible explanation. Importantly, abdominal hemorrhage is a dynamic process; time is required for its volume to increase and become detectable by ultrasound.[17] Blackbourne found that the sensitivity increased from 31.1% to 72.1% after a mean interval of 250.1 minutes between US examinations. We could not confirm this because, in our setting, time intervals between US examinations are much shorter than theirs. The maximum interval is never longer than the duration of patient contact: a mean of 42.6 minutes.

Our findings contrast with the sensitivity of 93%, and specificity of 99% that Walcher reported.[10] We speculate the main explanation is that they used emergency department ultrasound or CT imaging as the gold standard while we compared to (more sensitive) CT imaging and laparotomy. To prevent bias, we scored every mention of free fluid in the reports. This strict protocol probably implicates that small and possibly irrelevant amounts of free abdominal fluid negatively impact PHUS sensitivity. Although small injuries and insignificant amounts of free abdominal fluid may often have no clinical implications and therefore are not relevant in the prehospital setting, we encourage physicians to remain vigilant and if possible repeat the examination, in accordance with earlier research.[2,18]

The few systematic reviews available question whether the reported beneficial influences of PHUS result in a better treatment for patients.[13,14] According to O'Dochartaigh, it seems evident, that PHUS has a beneficial influence on diagnostics and logistics (the appropriate mode of transportation and destination hospital). Impact on survival, morbidity, and recovery time that might result from improved treatment, however, was not found. Stengel reported in his review that negative emergency department US examinations might lead to a decrease in additional imaging causing an undesired and possibly detrimental delay in treatment of the patients with false negative PHUS results.[13] They suggested the impact of US examination to be non-inferior at best.

We strongly agree with O'Dochartaigh that PHUS is beneficial. In our study, the proportion of policy changes is smaller than found in other studies, but it demonstrates that PHUS provides a significant contribution to medical decision making. It aids in selecting the most suitable trauma center, provides valuable extra time for trauma team preparation and potential operating and radiology room clearing. Moreover, PHUS probably influences patient care on many more levels, such as the urgency to act as experienced by the HEMS team. This impact will often not be reported or even acknowledged by physicians, and therefore we speculate our study underestimates the true scale PHUS-impacted patient care. Focusing on medical policy changes alone is probably insufficient to estimate the true value of PHUS. Using PHUS to confirm previous conclusions and justify a plan of work is equally important.

HEMS physicians often decide to refrain from escorting a patient to the hospital. Such a decision is based on more factors than the PHUS findings alone. Prehospital assessment of patients includes the trauma mechanism or illness, additional history taking, physical examination, and repeated measurements of vital signs. Nevertheless, in 53 patients, physicians indicated that PHUS impacted their decision not to escort the patient to definitive care.

Therefore, we speculate that PHUS rarely changed but more likely supported the physician's decision that transferring care to the ambulance paramedics was adequate. When a lower level of care was planned, PHUS was probably more supportive of this plan than that it was the sole cause for the plan to change. When these supported decisions are left out of the total, decisions are impacted in 132 (8.6%) of the PHUS examinations and in 126 (8.4%) of the patients. Although changing to lower level of care results in earlier re-availability of the HEMS team for subsequent scrambles or other patients in a multi-victim situation, and reduced operational costs, the reassurance might be justified only temporarily. Therefore, it may be unwise to rely on PHUS findings alone. We share Stengel's concern and therefore argue it might be prudent to change emergency (prehospital) protocols into a standard two-time abdominal PHUS regime. Such a regime, however, may not be feasible in the time-critical prehospital situation where other procedures, including transportation, have priority. In many cases, additional emergency department imaging is appropriate.

Strength and Limitations

The large sample of PHUS examinations (n = 1631) and the large subpopulation transported to our trauma center (n = 594) is a major strength of the study. Another strength is the way we handled the missing data on the PHUS-specific notes (970 out of 1631) resulting in only 92 cases being excluded.

There are also significant limitations. The conclusions from this single center study might not apply to other HEMS operations. The retrospective design and the database not designed for the study may have led to another standard of record keeping and recall bias; abdominal US examinations might have been performed but not recorded. Not every physician was trained in PHUS from day one leading to less ultrasound examinations in the first years of the study period. Experience of the physicians with PHUS is initially limited and is expected to increase over time. This might influence the diagnostic performance although we couldn't demonstrate an improvement some time after the introduction of PHUS in our service. Such an effect is probably blurred by the ever-changing pool of active HEMS physicians.

The impact of US on treatment decisions was self-reported by the physicians. This introduces a high risk of bias. For follow-up studies, efforts to reduce the extent of bias should be undertaken. Furthermore, the retrospective design allows for the occurrence of selection bias even though this was minimized through our methods.

Conclusion

Prehospital abdominal ultrasound examinations performed by the Nijmegen HEMS impacts patient care in 12.6% of cases. This justifies its continued prehospital use. Low sensitivity should encourage health care providers to remain vigilant in case of negative PHUS and to consider repeating the examination. PHUS is gaining ground, and we are convinced that future scientific efforts should be directed in this way.

Acknowledgements

R. Ketelaars and J. J. M. Holtslag contributed equally to the manuscript.

7

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7

Chapter 8

Prehospital echocardiography during resuscitation impacts treatment in a physician-staffed helicopter emergency medical service: an observational study

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Abstract

Background

Patients in cardiac arrest must receive algorithm-based management such as basic life support and advanced (cardiac) life support. International guidelines dictate diagnosing and treating any factor that may have caused the arrest or may be complicating the resuscitation. Ultrasound may be of potential value in this process and can be used in a prehospital setting. The objective is to evaluate the use of prehospital ultrasound during traumatic and non-traumatic CPR and determine its impact on prehospital treatment decisions in a Dutch helicopter emergency medical service (HEMS).

Methods

We conducted an observational study in cardiac arrest patients, of any cause, in whom the Nijmegen HEMS performed CPR with concurrent echocardiography.

The participating physicians had to adhere to Advanced Life Support protocols as per standard operating procedure. Simultaneous with the interruptions of chest compressions to allow for heart rhythm analysis ultrasound-trained HEMS physicians performed echocardiography according to study protocol. The HEMS nurse and physician recorded patient data and data on impacted (supported or altered) patient treatment decisions.

Results

From February 2014 through November 2016, we included 56 patients who underwent 102 ultrasound examinations. Sixty-two (61%) ultrasound examinations impacted 78 treatment decisions in 49 patients (88%). The impacted treatment was related to termination of CPR in 32 (57%), fluid management (14%), drugs selection and doses (14%), and choice of destination hospital (5%). Causes of cardiac arrest included trauma (48%), cardiac (21%), medical (14%), asphyxia (9%), and other (7%).

Conclusions

Prehospital echocardiography has an impact on patient treatment and may be a useful tool to support decision-making during CPR in a Dutch HEMS.

Introduction

Patients suffering from cardiac arrest must be treated immediately using algorithm-based management such as basic life support (BLS) and advanced life support (ALS). International resuscitation guidelines stress the importance of diagnosing and treating any factor that may have caused the arrest or may be complicating the resuscitative effort.[1–4] These guidelines recognize ultrasound to be of potential value in this process.

Peri-resuscitation ultrasound may be useful to identify treatable causes such as pericardial tamponade, cardiogenic shock, myocardial insufficiency, signs of pulmonary embolism, or hypovolemia.[5,6] Moreover, it may differentiate between false and true pulseless electrical activity (PEA), a pulseless state respectively with or without any cardiac contractions. Detection of cardiac activity on ultrasound may be an early sign of return of spontaneous circulation (ROSC) and is a good predictor of survival.[7,8]

Previous studies have demonstrated the feasibility of the application of ultrasound during in-hospital and out-of-hospital cardiopulmonary resuscitation (CPR).[9] Integrating it in current ALS algorithms is achievable while maintaining strict protocol adherence.[10]

Although the added value of ultrasound in ALS has been suggested, the question remains how it affects patient care and decision-making in the specific setting of a helicopter emergency medical service (HEMS). We sought to evaluate the use of prehospital ultrasound during traumatic and non-traumatic CPR and determine its impact on patient treatment in a Dutch HEMS.

8

Materials and methods

Design

We performed an observational study between February 2014 and November 2016. Ethical approval was obtained from the regional ethics review board of Arnhem/Nijmegen and they waived the requirement to obtain written informed consent (2014/112).

Recruitment and setting

In the Netherlands, four physician-staffed HEMS are operational 24 hours per day, all carrying a portable ultrasound machine. They are supplemental to a high-quality network of paramedic-staffed ground ambulances. The Nijmegen HEMS is stationed at the Volkel Air Force Base, covering an area of approximately 10,000 square kilometers, servicing a population of 4.5 million. Every physician is trained to perform an extended focused assessment with sonography for trauma (eFAST) examination, and basic echocardiography. In recent years, our HEMS conducted on average 2341 missions, increasing yearly by 13%. Typically, ground ambulances handle most resuscitations. However, on their or the dispatch center's request the HEMS aids in about 200 resuscitations including 50 children (< 18 years of age) yearly.

We included every patient that underwent CPR with concurrent echocardiography performed by our HEMS of which a dedicated case report form (CRF) was filled out. Exclusion criteria were the discontinuation of CPR or an indication to perform immediate thoracotomy in case of a (single) penetrating chest injury with loss of circulation no longer than 10 minutes.

The HEMS database that holds a record of every mission and every patient treated was examined to describe the base population of which this study's population is a subset.

Protocol

We used two different portable ultrasound machines during the study: a NanoMaxx® and a MicroMaxx® machine (Fujifilm SonoSite Inc., Bothell, WA, USA) both equipped with a 5–1 MHz broadband phased-array cardiac transducer.

Physicians were requested to treat the cardiac arrest patients in the usual way. ALS protocols with minimal interruptions of chest compressions had to be respected. Priority had to be given to heart rhythm analysis and defibrillation, establishing IV access, administration of

drugs and IV fluids, securing the airway, adequate ventilation, release of (suspected) tension pneumothorax, stopping any life-threatening bleeding, and treatment of other possible reversible causes.

After these interventions, or concurrent when enough caregivers were available, HEMS physicians were requested to perform an ultrasound examination of the heart and pericardium through a sub-xiphoidal view at pre-defined moments in the ALS algorithm. The physician prepared the examination by positioning the ultrasound probe in the subxiphoidal region with an estimated optimum location, probe angle, and machine settings while continuing compressions.

The physician performed the first examination as soon as possible after arrival on-scene, then after every five two-minute cycles of compressions, and finally, right after return of spontaneous circulation (ROSC) or when considering the termination of CPR, as suggested by Breitkreutz et al.[5]

The timing of echocardiography had to be in the same window where chest compressions are interrupted to allow for heart rhythm analysis. Interruption of chest compressions had to be kept to a minimum. The algorithm of the American Heart Association (AHA) emphasizes to minimize the duration of the interruptions to stay (well) below ten seconds.[3] The European Resuscitation Council (ERC) states the entire process of defibrillation should be achievable within a five-second interruption.[1] We instructed the participating physicians to respect the latter timeframe.

Additional ultrasound examinations of the chest and abdomen were performed depending on the discretion of the physician, but without interrupting chest compressions.

Data processing

If time allowed, the flight nurses recorded on-scene data simultaneous with every ultrasound examination: time, heart rhythm, palpable pulse, end-tidal CO_2, and the physician-reported ultrasound image quality and global myocardial function.

The CRF, specifically designed for this study, was filled out by the physician after return to base. Data recorded were: (estimated) time of cardiac arrest, start of BLS, initial observed heart rhythm, occurrence and timing of ROSC or termination of resuscitation. Additionally, we recorded ventricular dimensions, pericardial fluid, other findings on ultrasound, impacted decisions, the location where ROSC occurred or the team terminated CPR (e.g. during transport or in-hospital). We scored the perceived ease of the entire procedure on a 1–10 numeric rating scale (NRS) where 1 = extremely difficult and 10 = extremely easy. We encouraged the HEMS-personnel to enter additional free text to supplement or clarify the data.

As part of regular operations, an electronic record is created on every mission and treated patient. Records are stored in the custom-made HEMS database stored on a secure server and backed up daily. We linked the CRFs to the database by mission ID and we extracted additional relevant data: date of birth, sex, estimated body weight, and cause of the cardiac arrest.

Data analysis

We entered the data from the forms and relevant data from the database into a Castor database (Ciwit B.V., Amsterdam, the Netherlands) for secure storage and to comply with good clinical practice standards. After data acquisition was complete, we used IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA) for analysis.

Statistical analysis

We report normally distributed data as mean ± standard deviation (*SD*), and data with a skewed distribution as median with an interquartile range (IQR). We used Tukey's hinge technique to determine the IQR. Spearman correlation coefficient was used to qualify the relationship between body weight and image quality and the reported ease of the procedure. We considered statistical significance at a p–value < .05.

Table 8.1 Demographics

	n (%)	Range	Mean ± *SD*
Age (years)	56	0–90	42.9 ± 27.6
0–17	11 (20)		
>= 18	45 (80)		
Gender			
Male	40 (71)		
Female	16 (29)		
Weight of adults (kg)	44	40–125	83 ± 18

SD, standard deviation.

Results

Patients' characteristics

Between February 1, 2014, and November 30, 2016, our HEMS performed 6694 missions in which we treated 3229 patients. HEMS physicians performed echocardiography during CPR according to study protocol and included 56 patients. A Consort diagram of the study population is displayed in Figure 8.1. Demographics are displayed in Table 8.1.

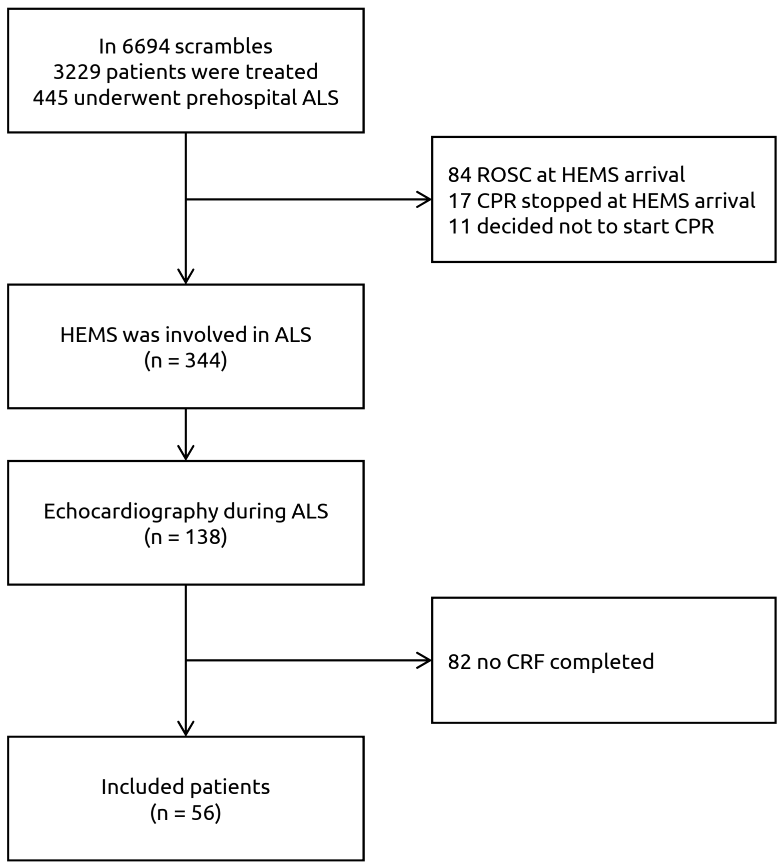

Figure 8.1 CONSORT diagram of the study population

ALS, Advanced Life Support; ROSC, return of spontaneous circulation; HEMS, helicopter emergency medical service; CPR, cardiopulmonary resuscitation; CRF, case report form.

Cardiac arrest

The causes of cardiac arrest are described for two age groups (under and over 18 years) and displayed in Table 8.2. The median delay starting BLS after the (estimated) occurrence of cardiac arrest (n = 50) was 2.5 minutes (IQR 0–8.25). CPR continued for a median of 32 minutes (IQR 23–50). The first ultrasound examination was performed 28 minutes (IQR 20–39) after the arrest.

ROSC occurred in 14 patients (25%). In nine patients (16%) ROSC occurred on-scene, in three (5%) during transport and in two (4%) in the emergency department. Hence, in 42 (75%) patients, circulation never returned. ROSC occurred in four of eleven children (36%).

In some, ROSC occurred only temporarily and eventually, the team terminated resuscitation. Overall, 36 (64%) died on-scene, 12 (21%) at the ED and five (8%) within 1–4 days after admittance. The latter group suffered from choking (n = 2), a cardiac event (n = 1), and sudden infant death syndrome (SIDS, n = 2). Three patients (5%) survived and suffered from choking (n = 2), and a cardiac event (n = 1).

Table 8.2 Distribution of causes of cardiac arrest (per age category)

Cause of cardiac arrest	Age < 18 years *n* (%)	Age >= 18 years *n* (%)	Total *n* (%)
Non-trauma	9	20	29 (52)
Cardiac	–	12 (27)	12 (21)
Medical (non-cardiac)	6 (55)	2 (4)	8 (14)
SIDS	2 (18)	–	2 (4)
Choking and asphyxia	1 (9)	4 (9)	5 (9)
Intoxication	–	1 (2)	1 (2)
Unknown	–	1 (2)	1 (2)
Trauma (high energy)	–	17 (38)	17 (30)
Traffic accident	–	13 (29)	13 (23)
Fall from height	–	2 (4)	2 (4)
Crush injury and asphyxia	–	1 (2)	1 (2)
Impact with a blunt object	–	1 (2)	1 (2)
Trauma (low energy)	2 (18)	8 (18)	10 (18)
Drowning	2 (18)	4 (9)	6 (11)
Hanging	–	3 (7)	3 (5)
Burns and inhalation trauma	–	1 (2)	1 (2)
Total	**11 (100)**	**45 (100)**	**56 (100)**

SIDS, sudden infant death syndrome.

Ultrasound

102 Ultrasound examinations were documented in 56 patients. Image quality was reported good (n = 60, 59%), moderate (n = 30, 29%) or poor (n = 12, 12%). The reported ease of the entire procedure (n = 40), comprising of one or more ultrasound examinations, was a median of 7 (IQR 5.50–9.00). In adults, image quality and ease of examinations were weakly negatively correlated to body weight, respectively $r = -.381$ ($r^2 = .145$; $p < .001$) and $r = -.347$ ($r^2 = .120$; $p = .045$), as displayed in Figure 8.2.

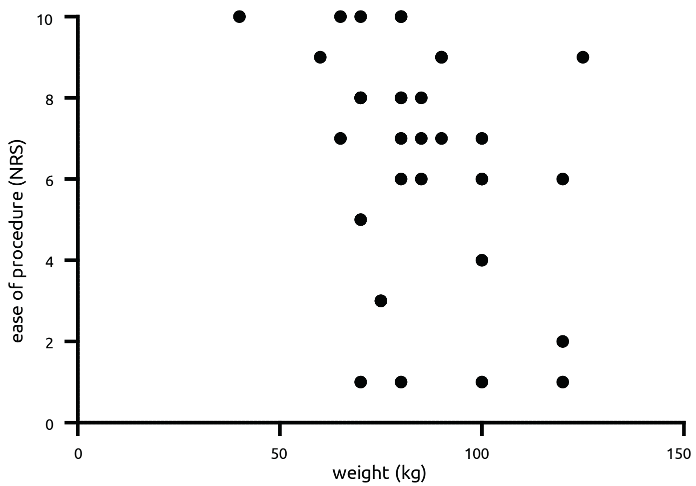

Figure 8.2 Scatterplot of adults' weight (18 years and over) and the ease of performing echocardiography during cardiopulmonary resuscitation

NRS, numeric rating scale (1–10); $r = -.347$ ($p = .045$).

Diagnoses made with echocardiography are displayed in Table 8.3. Additional ultrasound findings of chest and abdomen were pneumothorax (five patients, 9%), pleural cavity free fluid (two patients, 4%), intraperitoneal space free fluid (four patients, 7%), collapse of the inferior vena cava (one patient, 2%) and other (fractured spleen, hypertrophic ventricle, absent lung sliding because of esophageal intubation; three patients, 5%).

Table 8.3 Findings of echocardiography

Observation	number of US examinations (%)
Cardiac dimensions	
Ventricular filling	
good	65 (64)
poor	9 (9)
no filling	11 (11)
LV dilatation	–
RV dilatation	3 (3)
Could not assess	17 (17)
Global cardiac function	
good	8 (8)
moderate	11 (11)
poor	15 (15)
standstill	62 (61)
could not assess	6 (6)
Pericardial fluid	
absent	87 (85)
some	5 (5)
could not assess	10 (10)

US, ultrasound; LV, left ventricle; RV, right ventricle.

Impacted treatment decisions

In 49 patients (88%) treatment decisions were impacted or supported based on ultrasound. In 32 patients (57%) ultrasound led to or supported the decision to terminate the resuscitative effort. In 21 patients (38%) it was indicated that at least once (in 29 of 102 examinations (28%)) ultrasound supported the continuation of resuscitation.

Of 102 ultrasound examinations, 62 (61%) impacted or supported management decisions. One examination may have led to multiple changes; 78 impacted decisions were recorded. The number of impacted decisions does not include 29 examinations where physicians reported continuation of resuscitation was influenced by ultrasound. This is not considered impacted treatment, but apparently echocardiography was perceived to have played a role in decision-making.

All reported decision changes are displayed in Table 8.4.

Table 8.4 Impact of ultrasound on treatment decisions

Change in decision	US examinations *n* (%)	Patients *n* (%)
Terminate resuscitation	33 (32)	32 (57)
More intravenous fluid administration	11 (11)	7 (13)
Less intravenous fluid administration	1 (1)	1 (2)
Adjust adrenaline dosage	4 (4)	4 (7)
Start dobutamine (inotropic drugs)	2 (2)	2 (4)
Start phenylephrine (vasopressors)	–	–
Administer heparine	2 (2)	2 (4)
Pericardiocentesis	–	–
Thoracostomy	4 (4)	4 (7)
Insert gastric tube	3 (3)	3 (5)
Transport to different hospital	3 (3)	3 (5)
Provide ED with additional information	4 (4)	4 (7)
Other[a]	11 (11)	10 (18)
Continue resuscitation[b]	29 (28)	21 (38)

US, ultrasound; ED, emergency department.
Note: multiple changes can be associated with one examination or one patient.

a. Re-intubation because of absent bilateral lung sliding; withholding inotropic drugs; confirmation of tube position; increase noradrenaline dosage; increase cardiac pacing power output; not performing thoracostomies; stop cardiopulmonary resuscitation (ultrasound ROSC).
b. Continuation of resuscitation was reported as a decision after echocardiography, but not considered to be a change in treatment decisions.

8

Discussion

The main finding of the study is that in 88% of patients ultrasound guided resuscitation influenced or supported treatment and other decisions. Most frequently reported were termination or continuation of resuscitation and increasing the infusion of IV fluids. This could be expected because prehospital ultrasound may yield information about conditions that are difficult to diagnose by other means during ongoing CPR. These findings suggest that ultrasound can be useful in guiding prehospital CPR management.

This study confirms the findings of previous studies that have shown that ultrasound can lead to treatment changes. Recently, O'Dochartaigh reported that 25% and 45% of prehospital ultrasound scans supported interventions in trauma and medical patients, respectively.[11] The type of ultrasound findings and interventions reported in our study were similar. Breitkreutz showed altered management in 66% of patients subjected to prehospital peri-resuscitation ultrasound and in 89% of patients undergoing CPR.[6] Shokoohi showed changes in management on the ED in undifferentiated hypotension varying between 11.9% and 30.5% for changes in treatment, diagnostic imaging, consultation and admission location.[12] Our observations have added new insight into the role of ultrasound in the specific prehospital population that is being resuscitated by ground ambulance personnel supported by HEMS physicians and nurses.

Strengths and limitations

The strength of this study is the specific setting in which it has been conducted which contributes to its originality. These findings might be applied to the more homogeneous team settings across European HEMS. Conversely, it may be difficult to apply these findings to non-physician-staffed HEMS, such as most U.S. services.

Carrying out a prospective study in a physician-staffed helicopter emergency medical service, especially in a CPR scenario, is challenging. Many external factors will influence the mixed team of health care workers and the patient and its environment. Working space and resources are often limited, time pressure is high, and personnel perceive pressure to perform. Furthermore, they are working in surroundings and with colleagues they are often unfamiliar with.

The design and specific setting of the study introduce several limitations. We performed echocardiography only in a limited number of cardiac arrest patients. An explanation could be that in our prehospital setting, with a considerable proportion of trauma victims, the

quality of ALS is vulnerable to the influence of previously identified unfavorable factors, such as emotional and physical stress of the caregivers, time, and environmental factors. In our operation with its heterogeneous case-mix and within a limited amount of time, essential assessments and actions take precedence over ultrasound. Furthermore, we do not use ultrasound by default (yet) in every patient, let alone in every cardiac arrest case. Therefore, the ultrasound machine is not always brought to the incident site initially. Still, when it is present on-scene, it is not always used. A common scenario is that shortly after arrival on-scene either ROSC occurs or the ground ambulance team has already decided to terminate the resuscitation. Thus, there has not been any opportunity for echocardiography during CPR. Also, we might have omitted to use ultrasound because the cause of cardiac arrest was obvious or further treatment was deemed futile (e.g., a major injury with extensive blood loss).

A major limitation is the high number of missing CRFs. We speculate that some of the reasons might be nonadherence to the protocol, a lack of time due to subsequent missions, or plain forgetfulness. Another could be the dismissal of the entire procedure due to poor image quality, or the impression the scan contributed nothing to patient management. So, this might have introduced bias and possibly have led to over or underestimation of overall image quality and impacted decisions.

Unfortunately, in our operation, it is not possible to bring an independent observer on-scene. Therefore, ultrasound images could not be independently reviewed. Also, the impact of ultrasound on patient management was self-reported by the physicians after return to base. This could not be reported more objectively and might introduce bias. For instance, the effort physicians are making to perform echocardiography might make them more inclined to find utility. Or, the delay before the form is filled and other interventions performed in the meantime, might make the physician underestimate any added value when finally filling out the CRF.

The most frequent impacts on management were termination or continuation of resuscitation and increasing the infusion of iv fluids. Although it sometimes appears the obvious choice to terminate resuscitative efforts, this decision is preferably supported by the entire team and is complex and multifactorial.[13] The knowledge that sonographic cardiac standstill, in stark contrast to coordinated cardiac activity, predicts very poor (if any) survival improves the process of making a decision.[7,8,14] We speculate this explains the number of times ultrasound supported termination of treatment, although not every observed cardiac standstill justifies this immediately. Additionally, displaying the cardiac activity (or the lack thereof) can be of great value while explaining the prognosis and its implications to relatives and caregivers.

Any positive sign of cardiac activity on ultrasound is encouraging to continue resuscitation.[7] But obviously, there can be many other reasons to continue such as improvements of the electrical cardiac activity or exhaled CO_2 concentration. Therefore, we did not include the continuation of resuscitation in the overall amount of changes per patient. Nevertheless, also in this scenario ultrasound has provided additional value to the decision-making process.

Besides providing valuable information about the heart and pericardium, ultrasound in this specific setting is useful detecting unintentional bronchial or even esophageal intubation (leading to hypoxia), (tension) pneumothorax, and causes of hypovolemia such as intraperitoneal bleeding or hemothorax.[15–18] This is reflected in the variation in affected treatment decisions.

We reported the ease of performing ultrasound examinations concurrent with CPR to be a median of 7 and there is a negative but weak correlation to body weight. Thus, prehospital cardiac ultrasound performed by HEMS physicians is not perceived to be very difficult. Besides the suggestion that body weight complicates ultrasound examination, many other factors may make visualization of the heart more difficult such as environmental factors, sunlight, the presence of clothes, and operating in the tight confinement of an ambulance. Significant difficulties with accessibility or visualization could have resulted in no ultrasound examinations being made at all, so this score may be biased.

Overall, most frequently reported impact is stopping or continuing treatment, and increasing fluid administration. This is based on the most obvious echocardiographic findings: standstill, contractions, or poor filling of the heart.

This study provides an informative overview of ultrasound and cardiac arrest in a Dutch HEMS setting and it shows that prehospital ultrasound may be of value during CPR. It supports management in the majority of cases and therefore we suggest for every comparable HEMS to consider bringing an ultrasound device to cardiac arrest scenarios. On-scene it can then be determined if it is indeed feasible and justifiable to use it.

Because the present study was not designed to determine any effect on outcomes we were unable to determine the effect of prehospital ultrasound on outcome and survival of resuscitation in our population. Hence, a future randomized experiment might add to our current knowledge about the value of ultrasound during CPR. However, such a study will probably be deemed unethical by our HEMS physicians since they began regarding ultrasound as an essential diagnostic tool.

Conclusions

In a physician-staffed HEMS, it is feasible to perform echocardiography in prehospital cardiac arrest. It impacts patient management decisions and may be a useful diagnostic tool to support decision-making in ongoing CPR. Most frequently, ultrasound imaging was used to support the decision to terminate the resuscitation.

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Part IV

Ultrasonography in a future prehospital application?

Chapter 9

Increase in intracranial pressure by application of a rigid cervical collar: a pilot study in healthy volunteers

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Abstract

Objectives

Rigid cervical collars are known to increase intracranial pressure (ICP) in severe traumatic brain injury (TBI). Cerebral blood flow might decrease according to the Kellie Monroe doctrine. For this reason, the use of the collar in patients with severe TBI has been abandoned from several trauma protocols in the Netherlands. There is no evidence on the effect of a rigid collar on ICP in patients with mild or moderate TBI or indeed patients with no TBI. As a first step we tested the effect in healthy volunteers with normal ICPs and intact autoregulation of the brain.

Methods

In this prospective blinded cross-over study, we evaluated the effect of application of a rigid cervical collar in 45 healthy volunteers by measuring their optical nerve sheath diameter (ONSD) by transocular sonography. Sonographic measurement of the ONSD behind the eye is an indirect noninvasive method to estimate ICP and pressure changes.

Results

We included 22 male and 23 female volunteers. In total 360 ONSD measurements were performed in these 45 volunteers. Application of a collar resulted in a significant increase in ONSD in both the left (β = .06, 95% confidence interval: .05….07, p < .001) and the right eye (β = .01, 95% confidence interval: .00….02, p = .027).

Conclusions

Application of a rigid cervical collar significantly increases the ONSD in healthy volunteers with intact cerebral autoregulation. This suggests that ICP may increase after application of a collar. In healthy volunteers, this seems to be of minor importance. On the basis of our findings the effect of a collar on ONSD and ICP in patients with mild and moderate TBI needs to be determined.

Introduction

Often, patients with head-injuries suffer from additional cervical spine injury. For decades, trauma victims have been immobilized routinely when cervical injuries could not be ruled out at the scene. Rigid cervical collars and spine boards were used during transportation in prehospital trauma care. As advocated in advanced trauma life support and prehospital trauma life support protocols, immobilization is continued until cervical spine injury is excluded.[1,2] To minimize secondary damage to the spinal cord, in-line immobilization will be continued during transportation and examination.[3] Several devices to help immobilize the cervical spine such as the Stifneck® rigid cervical collar are commercially available.

The application of rigid cervical collars increases the intracranial pressure (ICP) of brain-injured patients in ICU settings.[4–6] This increase in ICP is attributed to compression of the internal jugular veins.[7,8] According to the Kellie Monroe doctrine, impaired venous drainage causes volume expansion inside the skull, which can increase ICP and lead to neurological deterioration.[1] Besides an increased ICP, local pressure of the collar may exacerbate discomfort and agitation in patients with mild or moderate TBI resulting in undesirable movement of the neck and an additional increase in ICP. More information on the effects of the cervical collar on the ICP is mandatory. However, outside of the ICU, it is not feasible to measure ICP directly.

Sonographic measurement of the optical nerve sheath diameter (ONSD) is a noninvasive, rapid method for indirect ICP monitoring.[9–11] The meninges around the brain are in continuum with the optical nerve sheath and cerebrospinal fluid percolates freely from the cranial cavity into the optical nerve sheath.[12,13] Previously, we showed that any change in ICP results in a simultaneous change in the ONSD in both eyes.[9]

In this study, the effects of the application of a rigid cervical collar on the ONSD were measured in healthy volunteers. We hypothesize that a rigid cervical collar increases the ONSD (through a raised ICP) in healthy volunteers with intact cerebral autoregulation.

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Methods

This blinded cross-over study was a single-center prospective research study. Volunteers were recruited at the medical library of the Erasmus University Medical Center. The volunteers were at least 18 years of age and did not have any self-reported medical history of ocular or intracranial disease. Both eyes were intact and functional. Every individual volunteer provided a written informed consent after reading the patient information form which was approved by the Ethical Committee of the Erasmus Medical Center, Rotterdam (MEC-2015-460).

Rigid collar and optical nerve sheath diameter

ONSD was measured simultaneously in both eyes by two experienced sonographers (IM and RK) who were blinded as to whether a collar was applied to the neck or not. Both sonographers are senior eFAST instructors since 2010 and have been working as helicopter emer-

Figure 9.1 Research set-up

gency medical service physicians since 2012. Both performed over 25 ONSD examinations before our study. Sonographers were also blinded to each other's measurements (Figure 9.1 and Figure 9.2). The upper part of the volunteer's head (from the nose up) was presented to the operators through a narrow opening in the center of a room dividing screen. Between every session, the sonographer was not allowed to see the participant, while a collar was being applied or not as per randomization. All four sessions of measurements were performed with the volunteers in a supine position on a table: two with and two without application of a Stifneck® (Laerdal Medical AS, Stavanger, Norway) rigid cervical collar.

Measurements were performed within two minutes after the application of the collar. Volunteers were instructed to breathe normally and not to talk or cough during the measurements. If coughing occurred, measurements were repeated. Randomization was achieved by rolling a die in one of six *collar regimes* (Table 9.1). A third researcher (BV) on the other side of the screen adjusted the size of the adaptable Stifneck® and applied it to the participants' neck as prescribed in the user manual (version and year). The cervical collar Velcro® was opened and closed again before every measurement, independent of application to the volunteer's neck

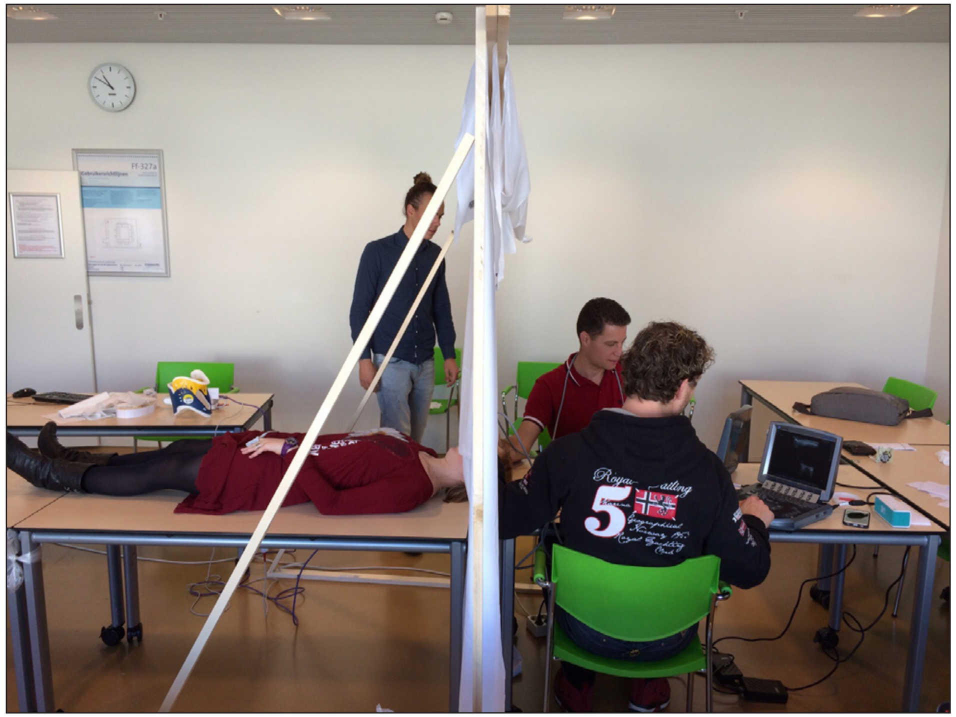

Figure 9.2 Research set-up

In the center of the image, the screen is shown that blocked the view to the subjects' necks.

Table 9.1 Rigid collar regime

Result of the die	Session 1	Session 2	Session 3	Session 4
1	0	0	1	1
2	0	1	0	1
3	1	0	0	1
4	1	0	1	0
5	1	1	0	0
6	0	1	1	0

0, no collar; 1, collar applied.

or not. This was done to blind the observers to audible clues as to the application or absence of the collar. During every session, heart rate, blood pressure, and blood oxygen saturation (SpO_2) were monitored noninvasively (Infinity M540; Dräger, Lübeck, Germany).

Images of the ONSD in the left and right eye were taken simultaneously with two identical M-Turbo® ultrasound machines (Fujifilm SonoSite Inc., Bothell, WA, USA). They were equipped with a 7.5 MHz linear-array transducer at ocular setting; mechanical index = 0.2. Axial measurements were carried out in B-mode. The images were frozen at the same time and ONSDs were measured by each sonographer on their machine with the internal calliper at 3 mm behind the retina as suggested before (Figure 9.3).[9–13] One sonographer measured all left eyes and the other sonographer measured all right eyes throughout the study.

Statistical analyses

Categorical variables are presented as numbers and percentages. Continuous data are presented with ranges and as mean ± *SD* when normally distributed or as median values and corresponding 25th and 75th percentiles when data were skewed. The intra-observer variability was calculated as the mean difference between two measurements for each eye/observer with and without application of a collar and reported as mean ± *SD*. To evaluate the effect of a collar on ONSD, linear mixed models were fitted. This method of analysis takes into account the correlated nature of repeated measures of the same participant. The models included volunteer as a random factor and collar, eye and collar by eye as fixed within-volunteer effects. IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA) and R (version 3.2.5, R Foundation for Statistical Computing, Vienna, Austria) were used.

Figure 9.3 Sonographic image of the optical nerve sheath diameter measured 3 mm behind the retina

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Results

Twenty-two male and 23 female volunteers were included. Their ages ranged from 18–31 (mean 20.3 ± 1.9) years. None used vasoactive medication of any kind. Systolic blood pressure (131.8 ± 8.7 mmHg), diastolic pressure (77.2 ± 5.6 mmHg), pulse (78 ± 10.8 min^{-1}), and peripheral oxygen saturation (98 ± 1%) were within normal limits. In total, 360 ONSD measurements were performed in 45 volunteers. Intra-observer variability varied between 0.001 ± 0.05 and 0.005 ± 0.05 (Table 9.2).

Table 9.2 Intra-observer and inter-observer variability

	Range ONSD (mm)	Average ONSD (mm)	Intra-observer variability
Left eye (observer 1)	0.38–0.78	0.54 ± 0.07	
Collar	0.40–0.78	0.57 ± 0.07	0.001 ± 0.05
No Collar	0.38–0.69	0.51 ± 0.06	−0.005 ± 0.05
Right eye (observer 2)	0.40–0.69	0.53 ± 0.06	
Collar	0.40–0.69	0.54 ± 0.07	0.003 ± 0.05
No Collar	0.42–0.66	0.53 ± 0.06	0.005 ± 0.05
Interobserver variability (observer 1 vs. observer 2)			
Collar		− 0.03 ± 0.07	
No Collar		0.02 ± 0.06	

ONSD, optical nerve sheath diameter.

The application of the collar resulted in a significant overall increase in ONSD (5.5 ± 0.7 mm vs. control 5.2 ± 0.6 mm, $p < .001$) (Figure 9.4). However, a significant effect of eye (left vs. right) and the interaction of eye and collar was observed (Table 9.3). Stratification on eye showed an increase of ONSD of 0.6 mm ($p < .001$) in the left eye and 0.1 mm ($p = .027$) in the right eye after application of the collar.

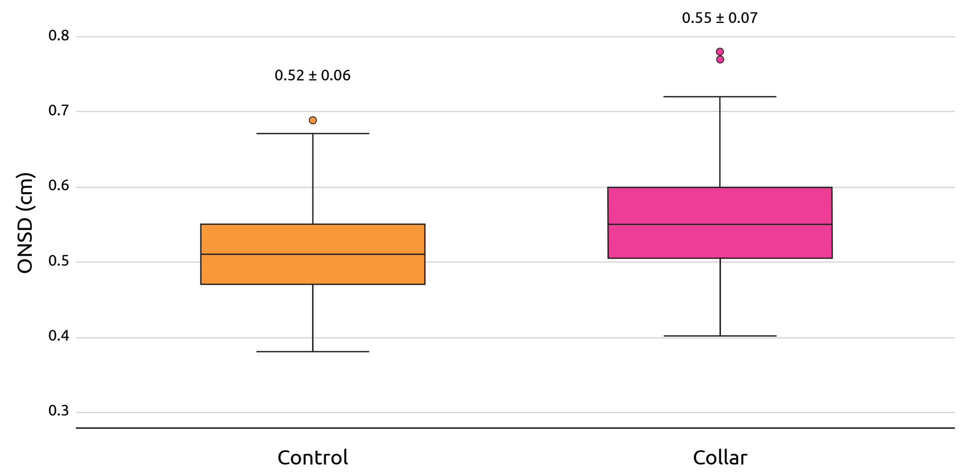

Figure 9.4 Optical nerve sheath diameter (ONSD) with and without a rigid cervical collar applied.

Table 9.3 Estimates of linear mixed-effect regression analyses on optical nerve sheath diameter

	Overall			Left eye			Right Eye		
	β	95% CI	*p*	β	95% CI	*p*	β	95% CI	*p*
Intercept	.53	.51, .54	< .001	.51	.49, .52	< .001	.53	.51, .54	< .001
Collar	.01	.00, .02	.047	.06	.05, .07	< .001	.01	.00, .02	.027
Left eye	–.02	–.03, –.01	.001						
Collar × Eye	.05	.03, .07	< .001						
Observations		360			180			180	

95% CI, 95% confidence interval.

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Discussion

We found in this study that application of a rigid cervical collar in healthy volunteers resulted in a statistically significant increase in the ONSD. This suggests that ICP will increase when a rigid cervical collar is applied. In healthy volunteers, this is probably clinically irrelevant because of maintained cerebral blood flow (CBF) by autoregulation mechanisms. When pressure compensation mechanisms, as described by Kellie and Monroe, are exhausted, and autoregulation is impaired after traumatic injury, an increase in ICP will compromise CBF and worsen secondary brain injury.[14]

It is assumed that the ICP in healthy volunteers is equal throughout the entire cranial cavity.[1,12,13] Toscano suggested no difference in ONSD distention in the left and right eye of heavily sedated and mechanically ventilated patients with increased ICP.[15] For practical reasons the positions of the sonographers were not changed during our experiment. One was seated on the left and one was seated on the right side of the table each with their own ultrasound machine (Figure 9.1 and Figure 9.2).

ONSD distention because of collar application was statistically significant in both eyes but we found an unexpected difference in effect in the left and the right eye. To our surprise the discrepancy between the left and right ONSD increased to 0.6 mm when a cervical collar was applied. This may have been caused by unequal pressure effects on the neck or in the brain because of the asymmetrical design of the collar. As pressure equilibration in the head may need more time than we assumed, our sonographic measurements might have been to short after application of the collar (< 2 min). An asymmetrical jugular diameter might have contributed toward the difference found as well.[16]

Furthermore, this left–right difference might have been because of a systematic measurement error (bias) between the sonographers and the ultrasound machines. However, the ultrasound machines were identical.

Although both examiners used the technique as described in the method section, a structural difference in performance might have occurred because of a difference in the experience of the two sonographers. One examiner (IM) had carried out previous research on ONSD, for the other (RK) this test was relatively new. However, the learning curve for performing ONSD measurements is reported to be as short as 10 examinations for experienced physicians.[17] Both examiners had carried out over 25 ONSD measurements before to this study in previous research or their work in the field. There was a structural difference in measurements of 0.2 mm between the results of the two examiners. Interobserver variability has been reported to be as small as 0.2 (range 0.1–0.5) mm for experienced sonographers.[11] Measuring structures this small might introduce a standard variation because of pixel density or software limitation of the ultrasound machines. Although Sonosite machines do not have to be calibrated periodically, a small difference in firmware might have introduced a systematic measurement error (M-Turbo®; Fujifilm SonoSite Inc.). In future research the sonographers should regularly switch sides to prevent this type of possible bias.

As we described before, the optical nerve sheath's response to ICP depends on its elasticity. The sheath contains the fewest trabeculae 3 mm behind the retina. This explains the hyper elasticity at this part of the sheath.[12] The cut-off point for ONSD for an increased ICP (> 20 mmHg) is still under debate.[9,10,13,15,17,18] Goeres suggests a difference in ONSD between sexes and advocate a different cut-off for men and women.[19] Maude suggests possible differences between ethnicities.[20] In our previous study we found a cut-off point of 5.0 mm representing increased ICP (> 20 mmHg) in sedated and intubated head-injured Dutch patients (67% men). As sheath elasticity varies between individuals ONSD measurement is a qualitative than a quantitative assessment of ICP.[9,18] Because of this we can state that the increased ONSD during collar application does represent an increase in ICP, but it is not possible to calculate the exact increase without knowing the elasticity coefficient of the sheath of that individual. The main question that remains, is whether or not this increase in ICP impairs CBF. If the ICP compensation mechanisms described by Kellie Monroe are exhausted, the slightest increase in venous volume in the head might result in an increase in ICP and a compromised CBF.

In daily clinical practice, let alone in a prehospital setting, CBF cannot be measured easily and reliably. CBF is directly related to cerebral perfusion pressure (CPP). CPP can be calculated as the mean arterial pressure (MAP) minus the ICP.[1] When autoregulation is disturbed after trauma, CPP should be maintained between 60 and 70 mmHg to prevent ischemia of the brain and cardiorespiratory complications of induced hypertension.[14] The slightest compromise of venous drainage from the head after application of a rigid cervical collar might impair CBF in TBI patients and may be counterproductive whenever ICP-lowering strategies are indicated.[21] In a healthy brain, cerebral autoregulation maintains CBF when systolic blood pressure fluctuates or venous blood temporarily pools in the head. In an injured brain, autoregulation might be altered or entirely dysfunctional, which makes the brain vulnerable to arterial pressure fluctuations and venous stasis.[21] This possible harmful effect of the collar and local pressure pain might explain the exacerbation of discomfort and agitation that we sometimes observe after application.[22]

Since 2016, Dutch prehospital trauma protocols differ from international advanced trauma life support and prehospital trauma life support protocols on the subject of cervical spine

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immobilization. Practice in the Netherlands is based on the evidence that the application of a rigid cervical collar increases ICP in severely brain-injured patients and the use of the collar is of questionable benefit in patients immobilized on a spine board or a vacuum mattress.[4–7, 23] Alternative strategies are used, such as manual in-line stabilization during extrication and vacuum mattress, and head blocks fixed with Velcro® straps to a spine board during transportation.[1,2,4–6,23,24]

Conclusions

Application of a rigid cervical collar significantly increases the ONSD in healthy volunteers with intact cerebral autoregulation. This suggests that ICP may increase after application of a collar. In healthy volunteers, the effect is limited and seems to be of minor importance. If baseline ICP is increased or autoregulation is impaired in a head-injured patient, this mechanism might worsen CBF. On the basis of our findings the effect of the collar on ONSD and ICP in patients with mild and moderate TBI needs to be determined.

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Part V

Chapter 10

Summary, discussion, and future perspective

R. Ketelaars

Summary and discussion

In this thesis, we focused on several aspects of emergency ultrasonography. We explored the literature, equipment and a selection of transducers. We evaluated its implementation and utility in the emergency department, the prehospital environment, and in future prehospital applications.

Prehospital and emergency ultrasonography is still very much in development. Partly, this is because the technology of ultrasound equipment is continuously improving. Weight, size, and costs are decreasing and image quality is improving. Therefore, general interest is growing, resulting in an increase in manufacturers and availability of (affordable) ultrasound devices on the market. Because of the increased availability, a rising number of nonradiologist healthcare providers are embracing ultrasonography for a growing set of indications. Similarly, the body of evidence in the literature is expanding.

In **Part I** of this thesis, background information on prehospital emergency ultrasonography and the technology was provided by means of a review of the literature and research on the equipment used.

In **Chapter 2**, a narrative review of the literature on prehospital ultrasonography was presented. In addition to the paper that was published in the Critical Ultrasound Journal the full search query was added as an appendix. We included every paper that provided additional information to create a comprehensive overview of all aspects of prehospital ultrasonography that are discussed in the literature. We discussed current and future applications of prehospital ultrasonography, both for diagnostic and therapeutic use. Additionally, we highlighted some applications of ultrasonography in the emergency department and in other settings such as clinical, military, and wilderness medicine, that seem suitable for general prehospital use. Some of the pitfalls of prehospital ultrasonography have been discussed such as the time investment of ultrasound examinations that not always will pay off, and the fact that the diagnostic accuracy of prehospital ultrasonography (PHUS) may be disappointing in some cases. Its accuracy depends to a large extent on the level of training and experience of the PHUS operator.

Since PHUS was introduced in the Nijmegen helicopter emergency medical service (HEMS), both a phased-array cardiac transducer and a linear-array transducer have been available. The phased-array transducer was used by most HEMS physicians as their first choice. This all-round transducer may be used for the extended focused assessment with sonography for trauma (eFAST) and prehospital rapid echo-evaluation program (PREP) examinations. Alternatively, a curved-array abdominal transducer has been chosen for all-round use by other Dutch HEMS. There is growing interest in new indications for prehospital ultrasonography, many of which would require a linear-array transducer that is necessary for imaging superficial anatomical structures. Moreover, due to the superficial anatomical structures that will be visualized in lung ultrasonography we hypothesized that this transducer might be preferable for this purpose.

In **Chapter 3**, three ultrasound transducers were compared for the diagnosis of pneumothorax. In patients scheduled for thoracoscopic lung surgery, we recorded ultrasound video clips before and after the surgeon opened the chest, creating a pneumothorax. These clips were blinded for the transducer type and were evaluated by prehospital HEMS physicians and experienced anesthesiology residents, all with experience in lung ultrasonography. The main findings were that these observers could detect pneumothorax with similar accuracy, regardless of the transducer type. The speed of the diagnosis and perceived image quality were best in the linear-array transducer clips, although the modest time gain probably has no clinical significance. The linear-array transducer's superior image quality, however, might be of benefit in the diagnostic workup of critically ill and injured patients in the dynamic prehospital environment.

Nevertheless, to be able to make the right diagnosis and initiate proper treatment it is important to focus on producing images that are accurate for their intended purpose rather than images that have great image quality. This was discussed by Fryback and Thornbury.[1]

The next question that must be answered is how these findings translate to the diagnostic work-up in real-world patients in the prehospital environment.

In **Part II**, two instances regarding the use of ultrasonography in the emergency department were highlighted.

We conducted semi-structured interviews with eight Dutch emergency physicians (EPs) to gain insight into how they implemented ultrasound in their emergency departments (EDs). At that time, in the Netherlands, no guidelines on ED-implementation, nor reports on the topic existed. We used convenience sampling and requested the PREP course venue to contact EPs employed by Level 2 trauma centers and who completed the two-day course 1–4 years prior to the interviews. Data saturation occurred after eight interviews. The aim of this qualitative study was to explore individual experiences of Dutch PREP-trained EPs who started routinely using US in their EDs.

The PREP course is discussed in more detail in the introduction of this thesis and the paper by Gerritse.[2]

In **Chapter 4**, we presented the elaborate report of this qualitative study. We concluded that Dutch EPs were highly motivated, but encountered many obstacles implementing ultrasonography in their EDs. Furthermore, they expressed the need for a certification system that allows recording their examinations and have experienced colleagues review the recorded scans when appropriate. Incentives for the EPs to start using ultrasonography were: (1) they had completed the course itself and acquired a new set of skills, (2) they were inspired by colleagues, and (3) they felt ultrasonography would be an important new tool in the emergency department. Important obstacles were a lack of confidence in their new skills, the lack of an actual ultrasound machine in the ED, and challenging cooperation with the radiologists.

It must be noted that although we reached data saturation after eight interviews, it is conceivable that a repeated series of interviews with another sample of comparable EPs could yield slightly different results. This is even more likely when such interviews were repeated today. The original interviews were conducted in 2014. Another weakness of this qualitative study is that it will be difficult to translate the results to ultrasound courses, EPs, and ED systems in other countries. Nevertheless, that was not the aim of the study.

As mentioned above, the interviews were conducted in 2014. Meanwhile, the Dutch national association of emergency physicians (Nederlandse Vereniging van Spoedeisende Hulp Artsen [NVSHA]) implemented ultrasonography as an integral part of the training of emergency medicine residents and adopted a certification program. Also, many Dutch EPs managed to implement ultrasonography in their EDs. They started using it for a myriad of indications, including eFAST, lung ultrasound, focused cardiac ultrasonography, ultrasound-guided regional anesthesia, and the evaluation of the deep venous system of the legs. Other examples of indications in the ED are the assessment for intrauterine pregnancy, of the urinary tract, acute right iliac fossa pain, and bone fractures. Many of these applications were discussed in **Chapter 2** when deemed feasible for emergency prehospital use.

Because of these recent developments, it would be interesting to conduct a follow-up study to evaluate the current experiences of EPs and to make a comparison with the experiences we described.

As part of HEMS physicians' efforts reaching out to the ED, we developed a training in ultrasound-guided regional anesthesia (UGRA), intended for EPs and residents. In a one-day course, we discussed, demonstrated, and practiced the performance of the 'blind' fascia iliaca compartment block and ultrasound-guided blocks of the femoral nerve and the nerves of the distal upper and lower extremity. In parallel, we devised a supervision system in which an

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expert anesthesiologist or an experienced resident in anesthesiology is available to assist or supervise the EPs while performing their first blocks.

In **Chapter 5**, we evaluated the performance of ultrasound-guided femoral nerve blocks performed by EPs and residents in 64 patients with proximal femoral fractures. They achieved effective pain relief in 69% of the patients after 30 minutes and in 83% after 60 minutes. The EPs were equally satisfied. They were all enthusiastic about the training and evaluated the procedure to be easy (score 8/10), successfully carried out (score 9/10), and of added value to patient care (score 9/10). In conclusion, these blocks were feasible and effective in the ED.

The subjects of this study were included through convenience sampling. No power calculation was performed before data collection started because the introduction of UGRA in the ED was evaluated after a certain time frame.

No adverse events occurred in this series of 64 patients. It may suggest that the performance of these US-guided nerve blocks by emergency physicians can be performed safely. However, with an extremely low incidence of adverse effects (intravascular injection, or neurologic damage) a much larger study should be performed in order to come to a definite conclusion regarding the safety of these procedures by nonanesthesiologists.

In the meantime, this training has been adopted and developed further by the Dutch Association for Regional Anesthesia (DARA) in collaboration with DEUS Ultrasound Courses and many more Dutch emergency physicians and residents have been and will be trained in UGRA.

In **Part III**, we focused on the impact of three ultrasound applications on prehospital patient care in the Nijmegen HEMS: ultrasonography of the chest, abdomen, and during cardiopulmonary resuscitation.

In **Chapter 6**, we presented a retrospective evaluation of 326 prehospital chest ultrasonography scans in 281 patients treated by the Nijmegen HEMS over a four-year period. We diagnosed a pneumothorax in 25 patients (9%), and a hemothorax in two patients (1%). Pulmonary contusion was only reported in two patients (1%). Based on PHUS, treatment changes were made in 60 patients (21%). Significant changes were: withholding a tube thoracostomy (n = 10 [4%]), while in three (1%) patients a tube thoracostomy was performed. Other changes concerned the patient destination for definitive treatment (n = 10 [4%]), and the termination of resuscitation (n = 9 [3%]).

The data on ten years of prehospital abdominal ultrasonography in critically ill and trauma

patients treated by the Nijmegen HEMS were evaluated in **Chapter 7**. We analyzed 1631 abdominal ultrasound scans performed in 1583 patients. Treatment decisions were impacted in 188 of 1495 patients (12.6%). The most important categories of impacted treatment were: (1) additional information provided to the destination hospital: the request to notify the trauma team, prepare packed red blood cells, and consider follow-up diagnostic imaging; (2) mode of transportation: most often, the HEMS crew handed over the care to the ambulance paramedics; (3) selection of the destination hospital for definitive treatment: triage up in 13 patients and triage down in 20 patients; (4) fluid management: more aggressive in 20 patients, more restrictive in nine patients.

The sensitivity of abdominal PHUS for the diagnosis of free intraperitoneal fluid was only 31% when compared with in-hospital computed tomography (CT) scans. A plausible explanation is that free intraperitoneal fluid accumulates gradually after trauma. Early after an incident, most fluid collections would be small or even non-existent at first. As time progresses, these collections might increase to an amount that is easily detectable. Thus, the interval between the incident and abdominal ultrasonography is a factor in the detection rate of fluid collections.[3] Another explanation is that CT is much more sensitive to small quantities of free intraperitoneal fluid than ultrasonography. Therefore, health care providers should remain vigilant in the event of a negative PHUS, especially in patients who are scanned shortly after the incident. Furthermore, they should consider repeating the examination. The specificity of abdominal PHUS was 97%. The significance of the diagnostic performance of abdominal ultrasonography for hemoperitoneum is that its utility is greatest when used as a rule-in tool: whenever PHUS shows free intraperitoneal fluid, it can be concluded with a high level of certainty that it is really there. But as always, the decision-making process, apart from PHUS, must take into account a full assessment by history taking (including the mechanism of trauma), physical examination, and measurements of vital signs.

Through a prospective, observational, diagnostic study, we studied prehospital focused echocardiography during cardiopulmonary resuscitation (CPR) in 56 patients in whose treatment the Nijmegen HEMS was involved. Echocardiography was performed within the narrow five-second interval that is allowed between two cycles of chest compressions and was repeated every ten minutes. The HEMS physicians reported whether and how treatment decisions were influenced.

This study and the impact of echocardiography on treatment decisions were presented in **Chapter 8**. In this population, cardiac arrest was often caused by trauma. This is probably due to the criteria that are being used by the dispatch centers for HEMS deployment. Treatment decisions were impacted (either changed or supported) in 49 patients (88%). The most important impacted decisions were: (1) termination of resuscitation (n = 32 [57%]);

(2) deliberate continuation of resuscitative efforts (n = 21 [38%]); (3) choice and dosage of administered drugs (n = 8 [14%]); (4) fluid management (n = 8 [14%]); and (5) choice of destination hospital (n = 3 [5%]). We concluded that peri-resuscitation focused echocardiography in the Nijmegen HEMS is feasible and impacts treatment decisions. Most frequently, ultrasonography was used to support the decision to terminate the resuscitation. Also, it may be a valuable tool to explain to relatives and fellow caregivers the severity of the situation before a futile resuscitation is actually stopped.

In comparison to this observational study, an experimental study design—in which subjects would be randomized to two groups and those groups would be compared—would yield a study that is more reliable and with more internal and external validity.

Moreover, an important weakness of the three published studies in **Chapter 6, 7, and 8** is that they reflect the specific situation of the Nijmegen HEMS. Due to the specific crew, skills, mode of operation, geography, and patient population, it might be difficult to generalize these findings to other (international) HEMS operations.

In **Part IV**, we discussed a novel application of ultrasonography that might prove to be useful in prehospital emergency medicine in the future: the sonographic measurement of the optic nerve sheath diameter.

In **Chapter 9**, we discussed 360 sonographic optic nerve sheath diameter (ONSD) measurements in 45 healthy volunteers. Both eyes (optic nerve sheaths) of every subject were measured four times. In half of the measurements, a rigid cervical collar was randomly applied to the subjects. By impeding venous drainage from the intracranial space, the application of a rigid collar might cause an intracranial pressure (ICP) increase. Subsequently, an increased ICP will lead to an increase in the ONSD.[4] The measurements in both eyes were performed simultaneously by two HEMS physicians with ample ultrasound experience, blinded for the presence of the collar. The main findings of the study were that the ONSD is higher if a collar is present than without a collar. We concluded that in healthy subjects, a rigid cervical collar causes an increase in the ONSD by impeding venous drainage from the skull, despite intact autoregulation of the cerebral circulation. We suspect that this effect may be even greater in traumatic brain injury (TBI) patients with an impaired cerebral autoregulation. Moreover, we concluded that sonographic ONSD measurements by (nonradiologist) HEMS physicians are feasible. This procedure can be applied in prehospital care and might prove to be valuable in the prehospital treatment of TBI patients with a decreased level of consciousness.

Conclusions of this thesis

1. A linear-array transducer is preferable for nonradiologists who perform lung ultrasonography for the diagnosis of pneumothorax. Its diagnostic accuracy for pneumothorax is similar to other transducers. However, the diagnosis is made slightly faster and it yields the best image quality.

2. Dutch emergency physicians have met challenges implementing ultrasonography in their emergency departments because of a lack of: incentives to start, confidence in their skills, ultrasound devices, or sufficient cooperation with radiologists. In present day, however, most of these hurdles have been overcome.

3. The Nijmegen emergency physicians and emergency medicine residents have successfully implemented ultrasound-guided regional anesthesia. In the emergency department, they now use ultrasound-guided regional anesthesia to achieve effective pain relief in patients with proximal femoral fractures.

4. Chest ultrasonography in the Nijmegen Helicopter Emergency Medical Service impacts treatment in 21% of patients. Most importantly, it has led to decisions to abstain from tube thoracostomies and it has impacted the mode and destination of patient transport for definitive treatment.

5. Abdominal ultrasonography in the Nijmegen Helicopter Emergency Medical Service impacts treatment in 12.6% of the patients. Most frequently, it allows the Helicopter Emergency Medical Service team to provide the destination hospital with additional relevant information to consider in their preparation. We found low sensitivity for free intraperitoneal fluid. This suggests that a negative abdominal ultrasound scan should always be interpreted in perspective to the clinical assessment of the patient and warrants repeated ultrasound scans in selected cases.

6. Focused echocardiography during cardiopulmonary resuscitation in the Nijmegen Helicopter Emergency Medical Service impacts treatment in 88% of the patients. Most frequently, it supports the decision to terminate the resuscitation.

7. Sonographic measurement of the optic nerve sheath diameter is feasible in healthy subjects and shows an increase in diameter if a rigid cervical collar is applied.

Future perspective

As noted before, ultrasound in healthcare will be used more and more often. This increase will undoubtedly continue in the years to come.

This thesis discussed the impact that ultrasonography has on prehospital and emergency medicine, and the additional utility and impact it might have in the future. Furthermore, technological developments such as the shift from piezoelectric crystals to semiconductor chips that enable a single broadband transducer to visualize both deep and superficial structures and sophisticated software fueled by deep learning and artificial intelligence will very soon be on the market. Various transducer types and the differences between them—as discussed in **Chapter 3**—will probably belong to the past. These developments will significantly facilitate acquiring and interpreting relevant, high-quality images, recognizing relevant structures, and taking various measurements. Less-skilled operators will also be able to use ultrasonography to help improve patient care.

Due to current and future applications and technological improvements, it could be beneficial to pursue a broader implementation of ultrasonography in the (Dutch) prehospital emergency medical services (EMS) and emergency departments.

First, the high standard of care provided by the Dutch land-based (ambulance) EMS could be even further enhanced by, for instance, guiding endotracheal intubation, facilitating intravenous access, guiding CPR, providing superior pain relief by means of UGRA, and by detecting or excluding abdominal aortic aneurysms in suspected individuals. The implementation could start by training a selected group of EMS personnel and by adding devices to selected EMS vehicles.

Secondly, the standard inventory of every Dutch HEMS should include an ultrasound device. The HEMS augments the land-based EMS and this augmentation should include additional diagnostic and procedural techniques. Therefore, it is recommended that every HEMS physician is trained in at least the eFAST/PREP protocol and possibly in additional techniques such as airway assessment, intravenous access, and UGRA. Recent developments such as extracorporeal life support (ECLS) and resuscitative endovascular balloon occlusion of the aorta (REBOA) may find their way to Dutch prehospital care and their chance of success will probably benefit from ultrasound. Moreover, any potential benefit of techniques such as ONSD measurements, and transcranial doppler for ischemic stroke should be further investigated.

Thirdly, every Dutch emergency physician should be trained in basic eFAST/PREP ultrasonography and every emergency department should at least have access to an ultrasound machine. Fortunately, in recent years basic ultrasonography has become an integral part of the training curriculum for emergency physicians. However, EPs should make an effort to perform diagnostic and procedural ultrasonography as often as possible to gain experience, maintain their skills, and expand their repertoire of indications. It would be recommendable to keep record of these procedures for certification purposes.

HEMS physicians, among others, should exercise caution in the event of a negative abdominal PHUS. They should be vigilant in blunt abdominal trauma patients, especially when they are scanned shortly after the incident or if physical examination or vital signs are abnormal. A repeated examination—on-scene or during transport—is recommended. The same advice is valid for EPs, but they should probably maintain a low threshold to request a CT scan.

In this thesis, the impact of prehospital ultrasonography on prehospital CPR in the Nijmegen HEMS was discussed. In many patients, it changed or supported the decision to terminate or continue resuscitation. In larger future studies with improved study design, the impact on prehospital—and in-hospital—resuscitation should be evaluated more precisely. Validity, reliability and generalizability must be better. Also, it would be commendable to evaluate other outcome parameters including morbidity and mortality in a larger, multicenter, population.

In anticipation of these studies and technological improvements, it could already be speculated that (prehospital) focused cardiac ultrasonography will play a more prominent role in the conduct of advanced life support (ALS). It will be beneficial to detect potentially treatable causes of cardiac arrest such as cardiac tamponade, pulmonary embolism, tension pneumothorax, severe hypovolemia (of any cause), and intra-abdominal bleed. Furthermore, ultrasonography will prove to be useful in the early detection of the return of spontaneous circulation (ROSC).

Maybe even, ultrasonography might someday earn its place in the so-called *chain of survival*... The chain of survival concept has evolved through decades of research in sudden cardiac arrest.[5] It consists of (1) early access—to activate the emergency medical services; (2) early basic life support (BLS)—to slow the rate of deterioration of the brain and heart, and buy time to enable defibrillation; (3) early defibril'lation—to restore a perfusing rhythm; (4) post resuscitation care—to stabilize the patient. For the time being, we provisionally added the fifth element—echocardiography—to the chain (Figure 10.1).

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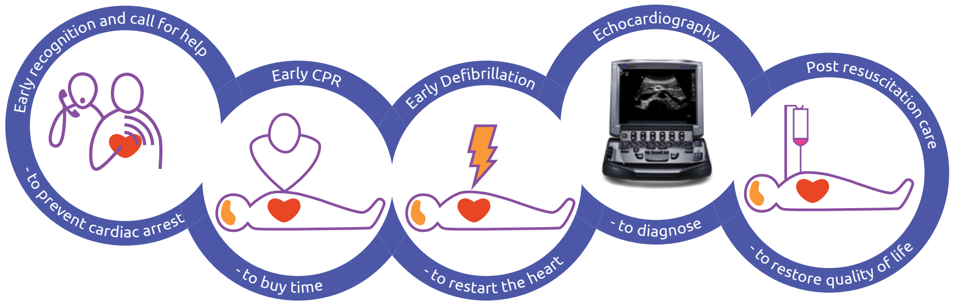

Figure 10.1 We suggest to extend the chain of survival with a fifth element

Focused echocardiography can be used to find treatable causes of cardiac arrest.

Research in prehospital emergency medicine is challenging because of the time-critical nature of the operation, the dynamic environment, and the high degree of heterogeneity in cases. Heterogeneity in the level of training and experience is also a factor. Due to limited physical space and operational limitations, helicopters, EMS vehicles, and their crews do not readily allow independent researchers to accompany the health care workers to ensure a standard level of data collection. For instance, a helicopter is able to lift only a limited amount of weight. The consequence of adding an additional 80 kg observer is that the amount of fuel must be reduced by 80 kg and hence the HEMS's range of operation will be significantly reduced. Moreover, performing CPR in the back of a moving ambulance hardly leaves any physical space for an extra observer to perform measurements.

Nonetheless, future research in prehospital ultrasonography could be aimed in a few distinct directions. First, it could be directed towards larger—international—multicenter studies involving larger samples with proper randomization and follow-up to allow the investigation of outcome parameters including morbidity and mortality. For example a thorough evaluation of prehospital focused cardiac ultrasonography during CPR or lung ultrasonography in the assessment for pneumothorax. Secondly, novel applications—such as airway evaluation or the confirmation of intraosseous vascular access needle placement—could be explored prospectively in pilot studies to prepare for the design of larger multicenter follow-up studies.

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Chapter 11

Samenvatting, discussie en toekomstperspectief

R. Ketelaars

Samenvatting en discussie

In dit proefschrift hebben we ons gericht op verschillende aspecten van spoedechografie. We verkenden de literatuur en hebben een aantal transducers vergeleken. We evalueerden de implementatie en het gebruik ervan op de afdeling Spoedeisende Hulp, in de prehospitale setting en in toekomstige prehospitale toepassingen.

Prehospitale en spoedechografie is nog steeds erg in ontwikkeling. Deels komt dit doordat de technologie van echoapparatuur voortdurend verbetert. Gewicht, omvang en kosten nemen af en de beeldkwaliteit neemt toe. Daardoor neemt in het algemeen de belangstelling toe, wat resulteert in een toename van fabrikanten en beschikbaarheid van (betaalbare) echotoestellen op de markt. Vanwege de toegenomen beschikbaarheid omarmt een toenemend aantal niet-radiologen echografie voor een groeiend aantal indicaties. Op dezelfde manier neemt de hoeveelheid wetenschappelijk bewijs in de literatuur toe.

In **deel I** van dit proefschrift werd achtergrondinformatie gegeven over prehospitale spoedechografie en de technologie door middel van een literatuurreview en onderzoek naar de gebruikte apparatuur.

In **hoofdstuk 2** werd een *narratieve review* van de literatuur over prehospitale echografie gepresenteerd. In aanvulling op het artikel dat werd gepubliceerd in het Critical Ultrasound Journal, werd de volledige zoekopdracht als appendix toegevoegd. We hebben elk artikel geincludeerd dat extra informatie toevoegde om zo een veelomvattend literatuuroverzicht over dit onderwerp te maken. We bespraken huidige en toekomstige toepassingen van prehospitale echografie, zowel voor diagnostisch als therapeutisch gebruik. Er werden ook enkele toepassingen van echografie op de afdeling Spoedeisende Hulp, in de kliniek en in militaire en wildernisgeneeskunde belicht, die ook geschikt lijken te zijn voor algemeen prehospitaal gebruik. Enkele valkuilen van prehospitale echografie zijn besproken, zoals de tijdsinvestering van echografie die niet altijd loont en het feit dat de diagnostische nauwkeurigheid van prehospitale echografie in sommige gevallen kan tegenvallen. De nauwkeurigheid ervan hangt in grote mate af van het trainingsniveau en de ervaring van de echografist.

Sinds de introductie van prehospitale echografie op het Nijmeegse helikopter Mobiel Medisch Team (MMT), is zowel een *phased-array* cardiale transducer als een *linear-array* transducer beschikbaar. De phased-array transducer werd door de meeste MMT-artsen gebruikt als de allround transducer van eerste keuze. Deze allround transducer kan gebruikt worden voor het *extended focused assessment with sonography for trauma* (eFAST) en het *prehospital rapid echo-evaluation program* (PREP). Andere MMT's kozen voor een

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curved-array abdominale transducer voor allround gebruik. Er is toenemende belangstelling voor nieuwe indicaties voor prehospitale echografie, waarvoor er vaak een linear-array transducer nodig is om oppervlakkige anatomische structuren af te kunnen beelden. Bovendien, vanwege de oppervlakkige anatomische structuren die bij longechografie worden gevisualiseerd, formuleerden we de hypothese dat deze transducer ook de voorkeur zou kunnen hebben bij longechografie.

In **hoofdstuk 3** werden drie echotransducers vergeleken voor de diagnose pneumothorax. Bij patiënten die voor thoracoscopische longchirurgie waren ingepland, maakten we echofilmpjes voor- en nadat de chirurg de thorax opende waarmee een pneumothorax werd gecreëerd. Deze filmpjes werden geblindeerd voor het type transducer en werden geëvalueerd door MMT-artsen en ervaren arts-assistenten anesthesiologie met ervaring op het gebied van longechografie. De belangrijkste bevindingen waren dat deze waarnemers pneumothorax konden diagnosticeren met een nauwkeurigheid die onafhankelijk was van het type transducer. De snelheid van de diagnose en de waargenomen beeldkwaliteit waren het best in de filmpjes gemaakt met de linear-array transducer, alhoewel de bescheiden tijdswinst waarschijnlijk geen klinische betekenis heeft. Echter, de superieure beeldkwaliteit van de linear-array transducer zou voordelig kunnen zijn tijdens diagnostiek bij ernstig zieke en gewonde patiënten in de hectische prehospitale omgeving.

Desalniettemin is het voor het stellen van de juiste diagnose en het inzetten van de juiste behandeling belangrijker om te focussen op het vervaardigen van accurate afbeeldingen die het beoogde doel dienen, dan op afbeeldingen met een geweldige beeldkwaliteit. Dit werd al beschreven door Fryback en Thornbury.[1]

De volgende vraag die moet worden beantwoord, is hoe deze bevindingen zich vertalen naar het diagnostische onderzoek bij echte patiënten in de prehospitale omgeving.

In **deel II** werden twee voorbeelden met betrekking tot het gebruik van echografie op de afdeling Spoedeisende Hulp (SEH) belicht.

We hebben semi-gestructureerde interviews afgenomen bij acht Nederlandse spoedeisendehulpartsen om inzicht te krijgen in de manier waarop zij echografie hebben geïmplementeerd op hun SEH. Op dat moment waren er in Nederland geen richtlijnen voor implementatie op de SEH, noch was er literatuur over het onderwerp. We hebben *convenience sampling* toegepast en de PREP-cursusorganisatie verzocht om SEH-artsen te benaderen die in een level 2 ziekenhuis werkten en de tweedaagse cursus 1–4 jaar vóór de interviews hadden voltooid. *Data saturation* werd na acht interviews bereikt. Het doel van deze kwalitatieve studie was om de individuele ervaringen van Nederlandse PREP-getrainde SEH-artsen te verkennen die inmiddels begonnen waren met routinematig gebruik van echografie op hun SEH.

De PREP-cursus wordt in meer detail besproken in de inleiding van dit proefschrift en in het artikel van Gerritse.[2]

In **hoofdstuk 4** presenteerden we het uitgebreide verslag van deze kwalitatieve studie. We concludeerden dat Nederlandse SEH-artsen zeer gemotiveerd waren, maar veel obstakels tegenkwamen die de implementatie van echografie op de SEH in de weg stonden. Bovendien hebben ze aangegeven dat er behoefte is aan een certificeringssysteem dat het mogelijk maakt om hun echo-onderzoeken te registreren en om ervaren collega's desgewenst de opgeslagen beelden te laten beoordelen. Beweegredenen voor de SEH-artsen om te beginnen met het gebruik van echografie waren: (1) ze hadden de cursus afgerond en een nieuwe reeks vaardigheden opgedaan, (2) ze werden geïnspireerd door collega's en (3) ze waren van mening dat echografie een belangrijk nieuw hulpmiddel zou zijn op de SEH. Belangrijke obstakels waren een gebrek aan vertrouwen in hun nieuwe vaardigheden, het ontbreken van een echotoestel op de SEH en uitdagingen in de samenwerking met de radiologen.

Hoewel we na acht interviews *data saturation* hadden bereikt, is het denkbaar dat een nieuwe reeks interviews met een andere steekproef van vergelijkbare SEH-artsen enigszins andere resultaten zou kunnen opleveren. Dit is zelfs nog waarschijnlijker wanneer dergelijke interviews vandaag de dag zouden worden herhaald. De oorspronkelijke interviews werden in 2014 afgenomen. Een ander punt van kritiek op dit kwalitatieve onderzoek is dat het waarschijnlijk niet eenvoudig is om de resultaten te vertalen naar echografiecursussen, SEH-artsen en SEH's in andere landen. Echter, dat was niet het doel van deze studie.

Zoals genoemd, werden de interviews afgenomen in 2014. Ondertussen heeft de Nederlandse Vereniging van Spoedeisende Hulp Artsen (NVSHA) echografie tot een vast onderdeel gemaakt in de opleiding van SEH-artsen en heeft het een certificeringsprogramma opgesteld. Ook zijn veel Nederlandse SEH-artsen er inmiddels in geslaagd om echografie op hun SEH te implementeren. Ze zijn ermee begonnen voor een groot aantal indicaties, waaronder eFAST, longechografie, gerichte cardiale echografie, echogeleide regionale anesthesie en de evaluatie van het diepe veneuze systeem van de benen. Andere voorbeelden van indicaties op de SEH zijn de beoordeling van de intra-uteriene zwangerschap, de urinewegen, acute pijn in de rechteronderbuik en botbreuken. Veel van deze toepassingen werden besproken in **hoofdstuk 2** wanneer ze ook haalbaar werden geacht voor prehospitale spoedechografie.

Vanwege deze recente ontwikkelingen zou het interessant zijn om een vervolgstudie uit te voeren om de huidige ervaringen van SEH-artsen te evalueren en een vergelijking te maken met de ervaringen die we hebben beschreven.

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Als onderdeel van de inspanningen van de MMT-artsen om samen te werken met de SEH, hebben we een training echogeleide regionaalanesthesie ontwikkeld, bedoeld voor SEH-artsen (in opleiding). In een eendaagse cursus bespraken, demonstreerden en oefenden we de uitvoering van het 'blinde' *fascia iliaca compartment block* en echogeleide zenuwblokkades van de n. femoralis en de zenuwen van de distale bovenste en onderste extremiteiten. Parallel hieraan hebben we een supervisiesysteem ontworpen waarin een ervaren anesthesioloog of een ervaren arts-assistent anesthesiologie beschikbaar is om de SEH-artsen te assisteren of superviseren terwijl ze hun eerste zenuwblokkades op de SEH uitvoerden.

In **hoofdstuk 5** evalueerden we de resultaten van echogeleide zenuwblokkades van de n. femoralis door SEH-artsen (in opleiding) bij 64 patiënten met een proximale femurfractuur. Effectieve pijnbestrijding werd bereikt bij 69% van de patiënten na 30 minuten en 83% na 60 minuten. De SEH-artsen waren ook tevreden. Ze waren allemaal enthousiast over de training en evalueerden de procedure als eenvoudig (score 8/10), succesvol uitgevoerd (score 9/10) en van toegevoegde waarde voor patiëntenzorg (score 9/10). Concluderend waren deze blokken op de afdeling Spoedeisende Hulp uitvoerbaar en effectief.

De patiënten in deze studie werden geïncludeerd via *convenience sampling*. Er werd geen powerberekening uitgevoerd voordat de dataverzameling begon omdat de introductie van UGRA op de SEH na een bepaald tijdsbestek werd geëvalueerd.

Er traden geen bijwerkingen op in deze reeks van 64 patiënten. Dat zou erop kunnen wijzen dat deze echogeleide zenuwblokkades veilig kunnen worden uitgevoerd door SEH-artsen. Bij een extreem lage incidentie van bijwerkingen (intravasculaire injectie of neurologische schade) moet echter een veel grotere studie worden uitgevoerd om tot een definitieve conclusie te komen met betrekking tot de veiligheid van deze procedures door niet-anesthesiologen.

In de tussentijd is deze training overgenomen en verder ontwikkeld door de Dutch Association for Regional Anesthesia (DARA) in samenwerking met DEUS Ultrasound Courses en zijn en worden nog veel meer Nederlandse SEH-artsen (in opleiding) getraind in echogeleide regionaalanesthesie.

In **deel III** hebben we ons gericht op de impact van drie toepassingen van echografie op de prehospitale patiëntenzorg bij het Nijmeegse MMT: echografie van de borstkas, de buik en tijdens de reanimatie.

In **hoofdstuk 6** hebben we een retrospectieve evaluatie gepresenteerd van 326 prehospitale echo-onderzoeken van de thorax bij 281 patiënten behandeld door het Nijmeegse MMT in een periode van vier jaar. We diagnosticeerden een pneumothorax bij 25 patiënten (9%) en een hematothorax bij twee patiënten (1%). Longcontusie werd slechts gemeld bij twee patiënten (1%). Op basis van prehospitale echografie veranderde de behandeling bij 60 patiënten (21%). Een belangrijke verandering was het ervan afzien om een thoraxdrain te plaatsen (n = 10 [4%]), terwijl bij drie (1%) patiënten juist wel een thoraxdrain werd geplaatst. Andere veranderingen betroffen de bestemming van de patiënt voor een definitieve behandeling (n = 10 [4%]) en het staken van de reanimatie (n = 9 [3%]).

De data van tien jaar prehospitale abdominale echografie bij ernstig zieke en traumapatiënten die behandeld werden door het Nijmeegse MMT werden geëvalueerd in **hoofdstuk 7**. We analyseerden 1631 abdominale echo-onderzoeken uitgevoerd bij 1583 patiënten. Behandelbeslissingen werden beïnvloed in 188 van 1495 patiënten (12,6%). De belangrijkste categorieën van beïnvloede beslissingen waren: (1) aanvullende informatie die werd verstrekt aan het ontvangende ziekenhuis: het verzoek om het traumateam op de hoogte te brengen, bloedtransfusie voor te bereiden en het overwegen van aanvullende beeldvorming; (2) wijze van transport: meestal droeg het MMT de zorg over aan de ambulancebemanning; (3) keuze van het ziekenhuis voor definitieve behandeling: *triage-up* bij 13 patiënten en *triage-down* bij 20 patiënten; (4) vochtbeleid: agressiever bij 20 patiënten, restrictiever bij negen patiënten.

De sensitiviteit van prehospitale abdominale echografie voor de diagnose van vrij intraperitoneaal was slechts 31% in vergelijking met de *computed tomography* (CT) onderzoeken in het ziekenhuis. Een plausibele verklaring is dat een hoeveelheid vrij intraperitoneaal vocht geleidelijk toeneemt na een trauma. Vroeg na een incident zullen de meeste vloeistofcollecties nog maar klein zijn of zelfs nog niet aanwezig. Pas met het verstrijken van de tijd kunnen deze collecties toenemen tot een hoeveelheid die gemakkelijker echografisch kan worden opgespoord. Het tijdsinterval tussen het trauma en abdominale echografie is dus een factor in de mate waarin vrij intraperitoneaal vocht kan worden gediagnosticeerd.[3] Een andere verklaring is dat een CT-onderzoek veel gevoeliger is voor kleine hoeveelheden vrij intraperitoneaal vocht dan echografie. Daarom moeten zorgverleners waakzaam blijven in het geval van een negatieve echo, vooral bij patiënten die vroeg na het incident worden gescand. Bovendien zouden ze moeten overwegen om het onderzoek na enige tijd te herhalen. De specificiteit van prehospitale abdominale echografie was 97%. Het belang van de diagnostische prestaties van abdominale echografie voor vrij intraperitoneaal vocht is dat het nut ervan het grootst is wanneer het gebruikt wordt als een *rule-in tool*: wanneer prehospitale echografie vrij intraperitoneaal vocht laat zien, kan met een hoge mate van zekerheid geconcludeerd worden dat er ook werkelijk vrij vocht aanwezig is. Maar zoals altijd moet men het besluitvormingsproces, naast prehospitale abdominale echografie, baseren op een volledige beoordeling van de patiënt door het afnemen van een anamnese (inclusief traumamechanisme), doen van lichamelijk onderzoek en het monitoren van vitale waarden.

Met een prospectieve, observationele, diagnostische studie bestudeerden we prehospitale gerichte echocardiografie tijdens de reanimatie van 56 patiënten waarbij het Nijmeegse MMT betrokken was. Echocardiografie werd uitgevoerd binnen het beperkte interval van vijf seconden tussen twee cycli van borstcompressies en werd elke tien minuten herhaald. De MMT-artsen rapporteerden of behandelbeslissingen werden beïnvloed en hoe.

Deze studie en de impact van echocardiografie op behandelbeslissingen werd gepresenteerd in **hoofdstuk 8**. In deze populatie werd circulatiestilstand vaak veroorzaakt door trauma. Dit is waarschijnlijk te wijten aan de criteria voor MMT-inzetten die door de meldkamers worden gehanteerd. Behandelbeslissingen werden beïnvloed (ofwel veranderd of ondersteund) bij 49 patiënten (88%). De belangrijkste beïnvloede beslissingen waren: (1) staken van de reanimatie (*n* = 32 [57%]); (2) voortzetten van de reanimatie (*n* = 21 [38%]); (3) keuze en dosering van toegediende geneesmiddelen (*n* = 8 [14%]); (4) vochtbeleid (*n* = 8 [14%]); en (5) keuze van het ziekenhuis voor definitieve behandeling (*n* = 3 [5%]). We concludeerden dat gerichte echografie tijdens de reanimatie bij het Nijmeegse MMT haalbaar is en dat het behandelbeslissingen beïnvloedt. Meestal werd echografie gebruikt om de beslissing te ondersteunen om de reanimatie te staken. Het kan ook een waardevol hulpmiddel zijn om aan familieleden en collega-hulpverleners de ernst van de situatie uit te leggen voordat een zinloze reanimatie daadwerkelijk wordt gestopt.

In vergelijking met deze observationele studie, zou met een experimenteel onderzoeksontwerp—waarbij patiënten gerandomiseerd in twee groepen zouden worden verdeeld en die groepen zouden worden vergeleken—een betrouwbaarder onderzoek opleveren met meer interne en externe validiteit.

Bovendien, een belangrijke punt van kritiek op de drie gepubliceerde studies in **hoofdstuk 6, 7 en 8** is dat ze enkel de specifieke situatie van het Nijmeegse MMT weergeven. Vanwege de specifieke bemanning, vaardigheden, werkwijze, geografie en patiëntenpopulatie, kan het moeilijk zijn om deze bevindingen te generaliseren naar andere (internationale) MMT's.

In **deel IV** bespraken we een nieuwe toepassing van echografie die in de toekomst nuttig zou kunnen blijken in de prehospitale spoedeisende geneeskunde: de echografische meting van de diameter van de mantel van n. opticus; de *optic nerve sheath diameter*.

In **hoofdstuk 9** bespraken we 360 echografische metingen van de *optic nerve sheath diameter* (ONSD) bij 45 gezonde vrijwilligers. Beide ogen (*optic nerve sheath*) van elke proefpersoon werden viermaal gemeten. Bij de helft van de metingen werd bij de proefpersonen willekeurig een stijve halskraag aangebracht. Door de veneuze drainage vanuit de intracraniële ruimte te belemmeren, kan de toepassing van een stijve halskraag een toename van de intracraniële druk (*intracranial pressure* [ICP]) veroorzaken. Vervolgens zal een verhoogde ICP leiden tot een toename van de ONSD.[4] De metingen in beide ogen werden gelijktijdig uitgevoerd door twee MMT-artsen met ruime ervaring met echografie, geblindeerd voor de aanwezigheid van de halskraag. De belangrijkste bevindingen van het onderzoek waren dat de ONSD groter is wanneer er een halskraag is aangebracht dan zonder halskraag. We concludeerden dat bij gezonde proefpersonen een stijve halskraag een toename van de ONSD veroorzaakt door belemmering van veneuze drainage vanuit de schedel, ondanks een intacte autoregulatie van de cerebrale circulatie. We vermoeden dat dit effect nog groter zal zijn bij patiënten met traumatisch hersenletsel (*traumatic brain injury* [TBI]) aangezien bij hen de cerebrale autoregulatie gestoord is. Bovendien concludeerden we dat echografische ONSD-metingen door MMT-artsen (niet-radiologen) haalbaar zijn. Deze procedure kan worden toegepast in de prehospitale zorg en zou er waardevol kunnen zijn bij de behandeling van TBI-patiënten met een verminderd bewustzijnsniveau.

Conclusies van dit proefschrift

1. Een linear-array transducer heeft de voorkeur voor niet-radiologen die longechografie toepassen voor de diagnose pneumothorax. De diagnostische nauwkeurigheid voor pneumothorax is vergelijkbaar met die van andere transducers. Echter, hiermee wordt de diagnose iets sneller gesteld en wordt de beste beeldkwaliteit verkregen.

2. Nederlandse spoedeisendehulpartsen kwamen obstakels tegen bij de implementatie van echografie op hun afdeling Spoedeisende Hulp vanwege: onvoldoende motivatie om te starten, een gebrek aan vertrouwen in hun eigen vaardigheden, geen beschikbare echoapparatuur of onvoldoende samenwerking met de radiologen. Heden ten dage zijn de meeste van deze hindernissen echter overwonnen.

3. De Nijmeegse spoedeisendehulpartsen (in opleiding) hebben succesvol echogeleide regionaalanesthesie geïmplementeerd. Op de afdeling Spoedeisende Hulp gebruiken ze nu echogeleide regionaalanesthesie en bereiken daarmee effectieve pijnverlichting bij patiënten met proximale femurfracturen.

4. Prehospitale echografie van de borstkas door het Nijmeegse Mobiel Medisch Team beinvloedt de behandeling bij 21% van de patiënten. Het belangrijkste was dat echografie aanleiding gaf om ervan af te zien een thoraxdrain te plaatsen en beïnvloedde het de wijze en bestemming van patiëntenvervoer voor de definitieve behandeling.

5. Prehospitale abdominale echografie door het Nijmeegse Mobiel Medisch Team beïnvloedt de behandeling bij 12,6% van de patiënten. Meestal helpt dit het MMT-team om het ontvangende ziekenhuis aanvullende relevante informatie te verstrekken die helpt bij hun voorbereiding. We vonden een lage sensitiviteit voor vrij intraperitoneaal vocht. Dit suggereert dat een negatieve abdominale echografie altijd moet worden geïnterpreteerd in het licht van de klinische beoordeling van de patiënt en dat herhaling van het echo-onderzoek bij specifieke patiënten nodig kan zijn.

6. Echocardiografie tijdens prehospitale reanimaties door het Nijmeegse Mobiel Medisch Team beïnvloedt de behandeling bij 88% van de patiënten. Meestal ondersteunt het de beslissing om de reanimatie te staken.

7. Echografische meting van de optic nerve sheath diameter is haalbaar bij gezonde proefpersonen en toont een toename wanneer een stijve halskraag wordt aangebracht.

Toekomstperspectief

Zoals al eerder opgemerkt, zal echografie in de gezondheidszorg steeds vaker toegepast worden. Deze toename zal ongetwijfeld nog doorgaan in de jaren en decennia die voor ons liggen.

Dit proefschrift gaat in op de impact die echografie heeft op de prehospitale en spoedeisende geneeskunde en op het mogelijke bijkomende nut en impact in de toekomst. Bovendien zullen technologische ontwikkelingen, zoals de verschuiving van piëzo-elektrische kristallen naar halfgeleiderchips die het mogelijk maakt om met een enkele breedbandtransducer zowel diepe als oppervlakkige structuren te visualiseren en geavanceerde software die gebruik maakt van deep learning en kunstmatige intelligentie, zeer binnenkort op de markt zijn. Verschillende typen transducers en de verschillen daartussen—zoals besproken in **hoofdstuk 3**—zullen waarschijnlijk tot het verleden gaan behoren. Deze ontwikkelingen zullen het verkrijgen en interpreteren van relevante, hoogwaardige beelden, het herkennen van relevante structuren en het uitvoeren van diverse metingen aanzienlijk vergemakkelijken. Minder geschoolde hulpverleners zullen dan ook echografie kunnen gebruiken die helpt om de patiëntenzorg te verbeteren.

Vanwege huidige en toekomstige toepassingen en technologische vooruitgang, zou het nuttig kunnen zijn om een bredere implementatie van echografie in de (Nederlandse) prehospitale spoedeisende hulpverlening en afdelingen Spoedeisende Hulp na te streven.

Ten eerste kan de hoge standaard van prehospitale zorg zoals die door de Nederlandse ambulancediensten wordt geleverd, verder worden verbeterd door bijvoorbeeld endotracheale intubatie voor te bereiden en te controleren, intraveneuze toegang te vergemakkelijken, reanimaties te sturen, superieure pijnverlichting te bieden door middel van echogeleide regionaalanesthesie en door aneurysmata van de abdominale aorta te detecteren of uit te sluiten. De implementatie zou kunnen beginnen met het trainen van een geselecteerde groep ambulanceverpleegkundigen en door geselecteerde voertuigen van de ambulancedienst uit te rusten met handzame echoapparatuur.

Ten tweede zou de standaardinventaris van elk Nederlands MMT een echotoestel moeten bevatten. Het MMT functioneert als een aanvulling op de ambulancedienst en zou ook aanvullende diagnostische en procedurele technieken moeten omvatten. Daarom wordt aanbevolen dat elke MMT-arts is opgeleid in ten minste het eFAST/PREP-protocol en mogelijk in aanvullende technieken zoals beoordeling van de luchtweg, verkrijgen van intraveneuze toegang en uitvoeren van echogeleide regionaalanesthesie. Recente ontwikkelingen zoals *extracorporeal life support* (ECLS) en *resuscitative endovascular balloon occlusion of the aorta*

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(REBOA) vinden mogelijk hun weg naar de Nederlandse prehospitale zorg en een succesvolle implementatie van deze technieken zou gebaat kunnen zijn bij de combinatie met echografie. Bovendien moet elk mogelijk voordeel van technieken zoals ONSD-metingen en transcraniële doppler bij een ischemische beroerte verder worden onderzocht.

Ten derde zou elke Nederlandse SEH-arts moeten worden opgeleid in basale eFAST/PREP-echografie en zou elke SEH tenminste de beschikking moeten hebben over een echotoestel. Gelukkig is basale echografie de laatste jaren een integraal onderdeel geworden van de opleiding tot SEH-arts. SEH-artsen zouden zich echter moeten inspannen om diagnostische en procedurele echografie zo vaak mogelijk uit te voeren om ervaring op te doen, hun vaardigheden te behouden en hun repertoire van indicaties uit te breiden. Het verdient aanbeveling om deze procedures bij te houden voor certificeringsdoeleinden.

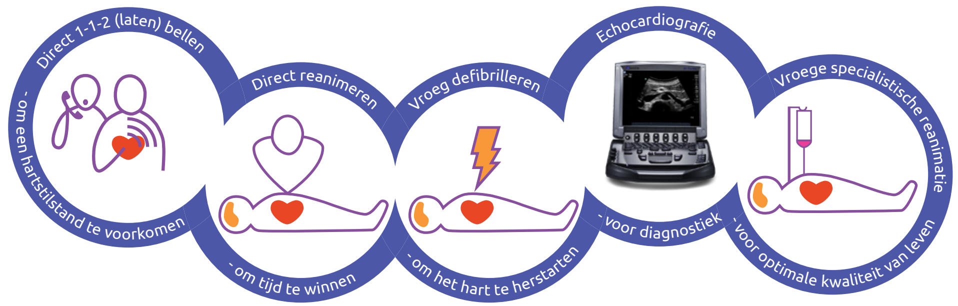
MMT-artsen, onder anderen, moeten op hun hoede zijn in het geval van negatieve abdominale echografie. Met name bij patiënten met stomp buiktrauma en zeker wanneer ze snel na het incident al worden geëchood of als het lichamelijk onderzoek of de vitale waarden afwijkend zijn. Een herhaald onderzoek ter plaatse of tijdens transport wordt aanbevolen. Hetzelfde advies geldt voor SEH-artsen, alhoewel zij waarschijnlijk laagdrempelig een CT-scan zullen aanvragen.

In dit proefschrift is de invloed van prehospitale echografie op de reanimatie door het Nijmeegse MMT besproken. Bij veel patiënten veranderde of ondersteunde het de beslissing om de reanimatie te staken of juist voort te zetten. In grotere toekomstige studies met een verbeterd onderzoeksontwerp zou de impact op prehospitale reanimaties—en reanimaties in het ziekenhuis—nog preciezer worden onderzocht moeten worden. De validiteit, reproduceerbaarheid en generaliseerbaarheid zullen beter moeten zijn. Ook zou het aanbevelenswaardig zijn om andere uitkomstmaten, waaronder morbiditeit en mortaliteit, te evalueren in een grotere, multicenter, populatie.

In afwachting van deze studies en technologische verbeteringen, zou er al gespeculeerd kunnen worden dat (prehospitale) gerichte cardiale echografie een prominentere rol zal gaan spelen bij de reanimatie ofwel *advanced life support* (ALS). Het zal van belang zijn om potentiële behandelbare oorzaken van hartstilstand te detecteren, zoals harttamponade, longembolie, spanningspneumothorax, ernstige hypovolemie (van welke oorzaak dan ook) en intra-abdominale bloedingen. Bovendien zal echografie van nut zijn bij de vroege detectie van het herstel van de eigen circulatie (*return of spontaneous circulation* [ROSC]).

Misschien zelfs, zou echografie ooit een plek in de zogenaamde *keten van overleven* kunnen verdienen... Het concept van de keten van overleven is geëvolueerd door tientallen jaren

van onderzoek naar plotselinge hartstilstand.[5] Het bestaat uit (1) vroegtijdig herkennen en alarmeren—om de medische hulpdiensten te activeren; (2) vroegtijdig reanimeren—om de schade aan de hersenen en het hart te vertragen en tijd te winnen om defibrillatie mogelijk te maken; (3) vroegtijdig defibrilleren—om het hartritme te herstellen; (4) postreanimatiezorg—om de patiënt te stabiliseren. Voorlopig voegden wij het vijfde element—echocardiografie—aan de keten toe (figuur 11.1).



Figuur 11.1 We stellen voor om de keten van overleven met een vijfde element uit te breiden

Gebruik gerichte echocardiografie om behandelbare oorzaken van een hartstilstand te detecteren.

Onderzoek naar prehospitale spoedeisende hulp is een uitdaging omdat tijd altijd een kritieke rol speelt, vanwege de dynamische omgeving en de hoge mate van heterogeniteit van de spoedgevallen. Heterogeniteit in het trainingsniveau en de ervaring speelt ook een rol. Vanwege beperkingen ten aanzien van de hoeveelheid fysieke ruimte en de manier van werken, laten helikopters en ambulances het niet gemakkelijk toe dat onafhankelijke onderzoekers de zorgverleners begeleiden om te zorgen voor een standaardniveau van gegevensverzameling. Een helikopter kan bijvoorbeeld slechts een beperkte hoeveelheid gewicht dragen. Het gevolg van het aan boord nemen van een extra waarnemer van 80 kg is dat de hoeveelheid brandstof met 80 kg moet worden verminderd waardoor de actieradius van het MMT aanzienlijk zal worden verminderd. Bovendien laat het uitvoeren van ALS achter in een bewegende ambulance nauwelijks ruimte over voor een extra waarnemer om metingen uit te voeren.

Desalniettemin kan voor toekomstig onderzoek op het gebied van prehospitale echografie aan een aantal richtingen gedacht worden. Ten eerste kan gedacht worden aan grotere—internationale—multicenterstudies met grotere steekproeven met de juiste randomisatie en follow-up om onderzoek van uitkomstparameters inclusief morbiditeit en mortaliteit mogelijk te maken. Bijvoorbeeld een grondige evaluatie van prehospitale gerichte cardiale echografie tijdens de reanimatie of longechografie bij de beoordeling voor pneumothorax. Ten tweede kunnen nieuwe toepassingen, zoals de evaluatie van de luchtweg of de bevestiging

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van de positie van een intraossale vaattoegang, prospectief worden onderzocht in pilotstudies om vervolgens grotere multicenter vervolgstudies te ontwerpen.

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Chapter 12

Appendices

List of abbreviations

ABCDE	airway, breathing, circulation, disability, exposure/environment
ACEP	American college of emergency physicians
ADHF	acute decompensated heart disease
ALS	advanced life support
ANOVA	analysis of variance
ANWB	royal Dutch touring club (Koninklijke Nederlandse Toeristenbond ANWB)
BLS	basic life support
BLUE	bedside lung ultrasound in emergency
BMI	body mass index
BNP	B-type natriuretic peptide
CAVEAT	chest, abdomen, vena cava, and extremities as an adjunct to acute triage
CBF	cerebral blood flow
CI	95% confidence interval
COPD	chronic obstructive pulmonary disease
CPAP	continuous positive airway pressure
CPP	cerebral perfusion pressure
CPR	cardiopulmonary resuscitation
CPU	central processing unit (of a computer)
CT	computed tomography
CTA	CT angiography
CXR	chest X-ray
DARA	Dutch association for regional anesthesia
DVT	deep venous thrombosis
ECLS	extracorporeal life support
ED	emergency department
eFAST	extended FAST
EMR	electronic medical record
EMS	emergency medical service
EP	emergency physician
ETT	endotracheal tube
EVLW	extravascular lung water
FALLS	fluid administration limited by lung sonography
FAST	focused assessment with sonography for trauma
FICB	fascia iliaca compartment block
FoCUS	focused cardiac ultrasound

GT	gastric tube
HAPE	high altitude pulmonary edema
HEMS	helicopter emergency medical service
Hz/kHz/MHz	rate of vibrations in cycles per second 1 kHz = 1,000 Hz; 1 MHz = 1,000,000 Hz
ICP	intracranial pressure
IQR	interquartile range
ICU	intensive care unit
IVC	inferior vena cava
LA	local anesthetic
LAST	local anesthetic systemic toxicity
LCI	lung ultrasound; cardiac ultrasound; inferior vena cava measurements
M-mode	motion-mode
MAP	mean arterial pressure
MCA	middle cerebral artery
MCI	multiple casualty incident/mass casualty incident
MMT	Mobiel Medisch Team
MRA	magnetic resonance angiography
MRI	magnetic resonance imaging
NPV	negative predictive value
NRS	numeric rating scale
NSAID	nonsteroidal anti-inflammatory drug
NVSHA	Dutch association of emergency physicians (Nederlandse Vereniging van Spoedeisende Hulp Artsen)
OHCA	out-of-hospital cardiac arrest
ONSD	optic nerve sheath diameter
OR	odds ratio
PAOP	pulmonary artery occlusion pressure
PEA	pulseless electrical activity
PHUS	prehospital ultrasound
PoCUS	point-of-care ultrasound
PPV	positive predictive value
PREP	programme rapide d'échographie d'un polytraumatisé; polytrauma rapid echo-evaluation program
REBOA	resuscitative endovascular balloon occlusion of the aorta
ROSC	return of spontaneous circulation
RTA	road traffic accident
RT	resuscitative thoracotomy
RUSH	rapid ultrasound in shock
SAMU	service d'aide médicale urgente
SD	standard deviation
SEH	afdeling Spoedeisende Hulp
SEM	standard error of the mean
SOP	standard operating procedure
TAP	transversus abdominis plane (block)
TBI	traumatic brain injury
TCCS	transcranial color-coded sonography
TCD	transcranial doppler
TOR	termination of resuscitation
UCA	ultrasound contrast agent
UGRA	ultrasound-guided regional anesthesia
US	ultrasound

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1. Sterk PJ, Rabe KF. The joy of writing a paper. Breathe (Sheff). 2008;4(3):224-32.

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Curriculum Vitae

Rein Ketelaars werd geboren op 1 september 1976 te Veghel. Na het behalen van zijn vwo-diploma aan het Zwijsen College in Veghel, begon hij in 1994 aan de studie Biologie aan de Katholieke Universiteit Nijmegen, thans Radboud Universiteit. Die studie werd al snel verruild voor Biomedische Gezondheidswetenschappen, thans Biomedische Wetenschappen. In 1995 werd hij ingeloot voor de studie Geneeskunde in Nijmegen. Tussen de bedrijven door was Rein actief lid bij de Nijmeegse Studentengezelligheidsvereniging Ovum Novum en was praeses in het academisch jaar 1999-2000. Daarnaast speelde hij basgitaar in Feestband FL!NK nog tot ver na de studententijd.

Rein heeft zijn artsexamen afgelegd in april 2003 en werkte vervolgens als anios op de afdeling Spoedeisende Hulp van het ziekenhuis Bernhoven, toentertijd in Veghel en Oss. In 2004 werd hij anios chirurgie in het Slingeland Ziekenhuis te Doetinchem. Na een functie als anios cardioanesthesiologie op de afdeling Intensive Care van het Amphia Ziekenhuis te Breda in 2006, begon hij in april 2007 met de opleiding tot anesthesioloog in het UMC St Radboud, thans Radboudumc, te Nijmegen (prof. dr. G. J. Scheffer). De perifere stage werd genoten in het Ziekenhuis Rijnstate te Arnhem (dr. E. T. Kamphuis). Het laatste halfjaar van de opleiding werd besteed aan een stage urgentieanesthesiologie bij het Mobiel Medisch Team (MMT) Lifeliner 3 (dr. N. Hoogerwerf). In juli 2012 volgde de registratie als anesthesioloog en bleef Rein in het Radboudumc en als MMT-arts op de Lifeliner 3.

Tijdens de opleiding tot anesthesioloog, in november 2009, werden onder leiding van dr. N. Hoogerwerf de eerste stappen gezet voor het wetenschappelijk onderzoek dat uiteindelijk heeft geleid tot dit proefschrift. In de loop der jaren werd met wisselende intensiteit aan de verschillende projecten gewerkt. In november 2016 werd het onderzoek en de inspanningen om alle projecten in dit proefschrift te bundelen in een stroomversnelling gebracht. Het resultaat ligt voor u.

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